ENVIRONMENTAL WATER POLLUTION AND ITS CONTROL

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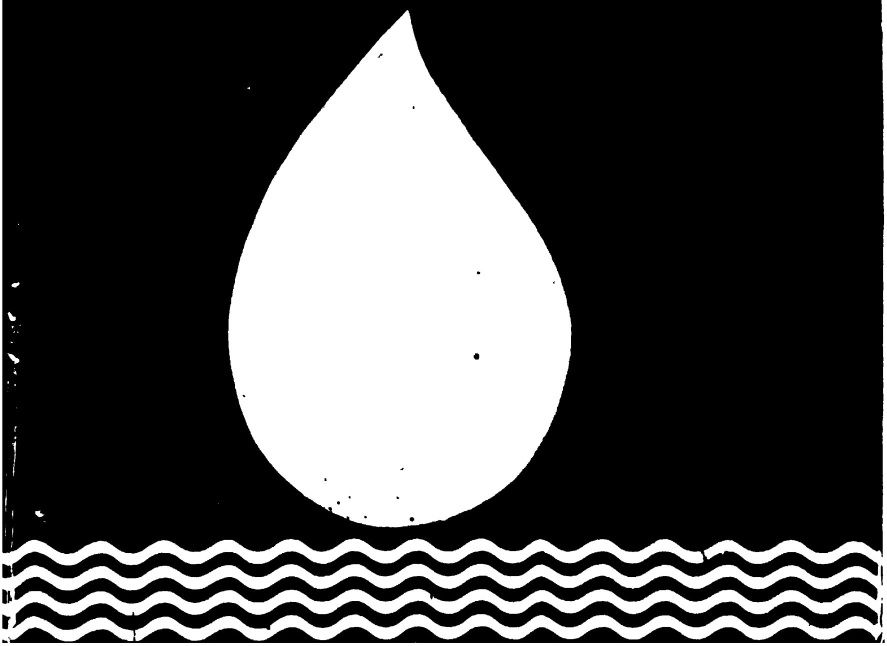

This book entitled "environmental pollution and its control" is a one-v... scientific discussion of water pollution, adverse effects on man and on environment and the various methods of its control. The book has been an attempt to keep pace with continuing rapid developments in the field of water pollution during the last twenty five years. The basic aim of the book is to present in a rigorous, quantitative manner many of the necessary fundamentals needed for the analysis of water pollution problem. If we are interested to preserve our future generations, environmental science and technology must play a vital and dominant role in designing one social and industrial structure for the management of water pollution to current and historical statistics have been given especially from Indian, Japanese, Canadian and American experiences in order to show the progress that has been attained during the last two decades in overcoming various aspects of water pollution and yet to demonstrate the magnitude of existing problems. This book, which assumes no previous knowledge of the subject has been based on the various methods which editors have followed over a number of years of teaching water pollution at all levels to be most easily understood by students. This book will meet the requirements of a wide range of readers who are involved directly or indirectly with water pollution including environmental students, research workers, civil and environmental engineers, operators of water treatment plants, environmental protection agencies, conservationists law enforcement officials and public administrators. An effort has been made to avoid detailed mathematical treatment but it has been necessary in some areas to use some simple mathematics.

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Preface

This book entitled "Environmental Water Pollution and its Control" is a one-volume scientific discussion of water pollution, its adverse effects on man and on environment and the various methods of its control. This book has been an attempt to keep pace with continuing rapid developments in the field of water pollution during the last twenty five years. The basic aim of the book is to present in a rigorous, quantitative manner many of the necessary fundamentals needed for the analysis of water pollution problem. If we are interested to preserve our future generations, environmental science and technology must play a vital and dominant role in designing our social and industrial structure for the management of water pollution. Current and historical statistics have been taken especially from Indian, Japanese, Canadian and American experiences in order to show the progress that has been attained during the last two decades in overcoming various aspects of water pollution and yet to demonstrate the magnitude of existing problems. This book, which assumes no previous knowledge of the subject, has been based on the various methods which editors have followed over a number of years of teaching water pollution at all levels to be most easily understood by students. This book will meet the requirements of a wide range of readers who are involved directly or indirectly with water pollution, including environmental students, research workers, civil and environmental engineers, operators of water treatment plants, environmental protection agencies conservationists, law enforcement officials and public administrators. An effort has been made to avoid detailed mathematical treatment but it has been necessary in some areas to use some simple mathematics.

During the compilation of this book, we have to draw upon the work of many authorities and seek the advice of students and colleagues to all of when the editors have been deeply indebted.

Finally the editors express their sincere thanks to the publishers and printer for bringing out this book promptly.

All comments from users on omissions or shortcomings will be highly appreciated.

—**The Editors**

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Introduction to Water Pollution

INTRODUCTION

During the last decades, parallel with rapidly developing technology, increasing populations and urbanization we have been witnessing alarming phenomena all over the world. In almost every country air, water and soil pollution, the decrease in arable land, the danger of radiation, the accumulation of solid wastes, the depletion of energy carriers and of mineral resources, the death of parts of the plant and animal kingdoms have been becoming dominant problems. The problems arising from increasing urbanization include the obsolescence of the infrastructure, the pollution of the city atmosphere, the lack and bad quality of the drinking water, overcrowding and traffic difficulties, the decrease in the areas of greenery, parks and generally the so-called damage done by civilization.

Different contaminants (pesticides, oil, sewage, faeces, detergents) and excessive use of fertilizers affect both the living organisms of the soil and the vegetation of higher plants. Approximately 900,000 t pesticides are applied yearly. Upto now some 80,000 t DDT has accumulated (Lang 1981). DDT can be detected in the entire living world and can also be found in significant quantities in the human body.

The growing load of environmental pollution gives rise to an increase in the number of so-called civilizational damage, that menace the whole of mankind. Because of the manifold and increased overstressing of the human organism, gastric ulcers, cardiac infarctions, chronic illnesses of the respiratory system, neurosis, etc. occur more frequently. Often different chemicals get into the human organism (Sos 1981). The occasional appearance of certain unidentifiable illnesses, like the Minamata-disease or the Itai-Itai-disease can also be traced back to the toxicity of chemicals.

Parallel to pollution of the environment and of the living world (air, water, soil) have been subject to environmental stresses and a demographic explosion may have to be reckoned with, around the year 2000. According to surveys of the UNO the world population will grow from 3 to 4-6 billion between 1960 and 2000. All these factors point to the danger of the upsetting of the natural environment. Others, on the contrary, express the view that with the appropriate means for the control of population growth in the hands of humanity (Szentagothai 1982) the demographic explosion could be evaded.

WATER RESOURCES OF THE WORLD

According to our present knowledge the total water resources of the world amount to 26.6 trillion t. Approx. 94.7% of this huge volume of water can occur in the lithosphere (rocky belt), its major part being bound to minerals which constitute the rock bed. This is known as bound water (other names : water of crystallization, water of constitution). These waters have been forming a part of the structure of minerals and get released only at high temperature. The remaining 5.3% can practically be found in the hydrosphere (water belt), the distribution of which is given in Table 6 (Entz 1964).

The oceans and seas form the greatest coherent volume of water to be found on the surface of the Earth. They have been covering 70.84% of the 510 million km² of surface area of our planet. Their depth exceeds, in more than one location, the height

of the highest peaks of the continents. On the surface of the continents water appears in a more scattered form, covering 2.5 million km² of its territory. From this, the area of fresh water amounts to 2 million km². The volume of fresh water has been small in comparison with that of seas and oceans (Table 1.1). It amounts to barely 0.4% of the surface area of the Earth and to approx. 1% of the area of the continents.

Table 1.1. Water resources of the hydrosphere

Location and state of stored water	Amount 10^{12} *t*	*Per cent*
Seas	1,380,000	98.900
Polar and mountain ice and snow	16,700	1.077
Fresh water	25	0.002
Water vapour in the atmosphere	13	0.001
Underground water	250	0.020
Total	1,396,988	100.000

In the Earth's interior, water is found in various forms of underground water. Capillaries of granular soils are filled with coherent soil water. Soil binds water by means of capillary action (soil moisture), though the existence of subterranean streams should also be mentioned.

The quantity of biologically bound water, in comparison with the above forms, has been somewhat insignificant. The biologically bound water implies water that forms part of the structures of plants and of the bodies of animals. The so-called transpiration water, transpired by plants in the course of their metabolism should also be considered. In the form of invisible vapour and the condensed water of clouds, finely distributed water has been also present in the atmosphere.

DEGRADATION OF WATER RESOURCES

Increased water consumption caused by urbanization and industrialization results in the lowering of the underground water-

table. For example, in Italy, around Milan, the underground water-table has sunk by 20 m, over a period of 20 years. In 1945, in Bologna, underground water could be found at a depth of 12 m ; today it is to be found at 45 m (Dajoz 1981). Industrial effluents and domestic sewage, detergents, pesticides and oil have been all polluting the rivers, lakes and seas. The death of living organisms in Lake Erie has been already known. There have been other alarming reports on dying seas (the Baltic), on the damage caused by oil-spills on marine-living organisms, on the Rhine having become a sewer, etc. The pollution of marine waters has been regarded as a matter for special concern as the sea's phytoplankton and particularly algae have been the world's largest oxygen-producing resources. Indications of water pollution have been multiplying in Hungary, too. To mention only a few: the river Sajo has become a lifeless water way, fish kills occur in Lake Balaton and periodically, polluting substances of smaller or greater quantity emerge in the rivers, bathing is forbidden along the Danube reaches of greater Budapest, etc. Because of the spread of newly established industrial plants, towns, resort-areas, water and gas pipelines, highways and roads, the area of arable land and that of natural plant cover, forests, meadows and marshes has decreased.

Because of erosion and salinisation, approx. 500 million ha of arable land has become infertile in the world (Lang 1971). One quarter of the arable land in China is eroded and 2.5 billion t of arable land is lost every year. The river Rhine carries 4.6 t of silt into the sea (Klausewitz et al. 1971). According to a report from the UNO, more than 10 million ha are lost from agricultural cultivation because of secondary salinisation (Szabolcs 1971). In Hungary, 150 million t of fertile soil has been carried away by rain-water (Madas 1973).

CLASSIFICATION OF NATURAL WATERS

Natural waters which have been comprising all the waters of the continents have been divided into two groups : seas and inland waters. Besides their vast extent and volume sea water can be

characterized by a mean 3.5% dissolved solid content of which 2.73% is salt (sodium chloride). The volume of inland waters has been less, their salt content being under 3%. The majority of them has been so-called fresh water, with a dissolved solid content under 0.05%.

Waters can be classified according to several principles like organic matter content, temperature conditions, turbulence, vegetation, etc. Particularly in the case of lakes, numerous classifications are used. From among them Thienemann's (1926) classification can be considered as the most comprehensive :

(*i*) Ground waters
(*ii*) Springs
(*iii*) Running waters (from brooks to rivers)
(*iv*) Standing water : lakes, lagoons, pond or swamps, temporary waters
(*v*) Waters of unusual temperature and chemical composition : thermal waters, snow and ice, sewage, brackish waters (with a salinity of 0.05-3%), highly-saline and natron (chemically rich) lakes and other waters having peculiar characteristics.

On the basis of the use of water domestic, industrial and agricultural sewage can be distinguished. These have been very different in their composition and even within a certain group great differences can be observed concerning their centent. As to the biological impact of substances to be found in sewages, they could be divided into two main groups : nutrients and biologically active substances, *i.e.*, poisons.

Organic matter utilizable by heterotrophic organisms (bacteria, worms, arthropods, etc.) form the first group of natrients, whereas the inorganic nutrients utilized by autotrophic organisms (algae) belong to the other one. In this context it should be mentioned that there have been two important water quality indicators : (*i*) The accumulation of decaying organic matter available for heterotrophic organisms results in nothing else but saprobity. (*ii*) The

amount of inorganic (mineral) substances available for algae represents the degree of trophicity.

Biologically active substances (poisons) have been forming two main groups. Group 1 is having inorganic matter (microelements : fluorine, zinc manganese, etc.: active residues : NO_3 ; different gases, etc.), whereas organic matter (detergents, plastics, pesticides, phenols and different kinds of tar) belong to Group 2. The toxic effect of waters, which can hinder or even prevent aquatic life, is expressed by toxicity as an index of water quality.

Sewage modifies the water quality of surface waters. It is established that downstream of the source of pollution, after a while, polluting matters gradually disappear and water regains its original state. This process is termed as self-purification. It has been the result of physical, chemical and biological processes in which living

Table 1.2. Forecast water demand and wastewater discharges (million m^3/year) (Illes et al. 1979)

	1965	*1970*	*1975*	*1980*	*2000*
Total water demand	3,700	4,800	6,400	8,700	10,500
Fresh water demand	1,600	2,100	2,800	3,900	5,800
Sewage discharges	390	500	665	900	1,200
Fully purified sewage	70	120	330	630	930

organisms have been playing the most important role. From among the physical factors, water movement, viscosity, temperature and light condition can be underlined. Hydrolysis and oxidation of polluting matters have been the most important chemical processes, interrelated with the metabolism of life communities, which take place in two phases. In the anaerobic phase (decomposition and actual decay) bacteria are able to decompose organic matter in the absence of oxygen. In the aerobic process, in the presence of oxygen besides bacteria also plant and animal organisms take part in decomposition. It has been however, impossible to determine the exact boundaries between the two processes.

Aquatic living organisms have been studied by numerous scientists. It is well established that the occurrence of certain organisms has been an indication of a particular degree of pollution. This can be explained by the fact that aquatic organisms have adapted themselves to the varying degree of pollution and to the differing chemical conditions derived from it. Among the organisms of the plant and animal kingdom, the single celled animals (Protozoa) have been of special importance, though there have been also other organisms which render it possible to assess the degree of water saprobity. In his classical work Liebmann (1962) distinguishes 4 degrees by which he characterizes the state of pollution by domestic sewage. (Table 1.3).

The polysaprobic type of water has been highly polluted with a great amount of protein, high molecular weight N-containing compounds, polypeptides, grease and their decomposition products. It is having an offensive odour. As oxygen is generally absent, the process of self-purification starts under anaerobic conditions. At the beginning of decomposition there has been a great number of bacteria present.

Table 1.3. Characterization of the degree of water pollution

Degree of pollution	*Saprobity*	*Colour of water*
Very severely polluted	Polysaprobic	red
Strongly polluted	α-mesosaprobic	yellow
Moderately polluted	β-mesosaprobic	green
Slightly polluted	Oligosaprobic	blue

The α-mesosaprobic type water has been characterized both by the increase of dissolved oxygen and by the presence of amino acids derived from the decomposition of proteins. Besides the still great number of bacteria, the presence of algae has been also significant. The oxygen demand has been still great, though the water does not smell so badly as polysaprobic sewages do. Waters of the β-mesosaprobic type get characterized by a significant oxygen content

for which there has been only little oxygen demand. While the number of bacteria decreases, it has been rich in other species and individuals of microscopic organisms. This life community has been very sensitive to the impacts of sewage.

The oligosaprobic water has been possessing a great amount of dissolved oxvgen, while the number of bacteria has been still insignificant. It is rich in species but poor in individuals. This life community reacts to changes in the composition of water very sensitively. Its members have been not capable of enduring poisonous substances even in very small concentrations. It has been not only the quality and quantity of living organisms that renders it possible to get information on the degree of water saprobity but also the chemical characteristics of the water (quantity of organic matter, biochemical oxygen demand, processes in connection with the oxygen cycle, etc.).

Due to the use of the agricultural use of chemical, pesticides, which belong to the class of biologically active substances, have become one of the most wide-spread poisons. According to the type of organism to be killed, nearly 200 poison types have been known (acaricide- mite-, larvicide (mosquito), nematicide (round-worm) killer, etc. Concerning their active ingredient they have been most varied (zinc and arsenic compounds, chlorinated derivatives, phenoxy derivatives, DDT and its derivatives, etc.). The number of the most frequently applied poisons exceeds 60. Numerous authors described tragic cases in foreign countries where lakes and rivers suffered from pesticide kills. These substances could be able to penetrate into the living-space in three ways : (*a*) by direct treatment of the water surface ; (*b*) by wind, from the treated arable land ; (*c*) from treated land, by way of water infiltration.

Data in the international literature appear to indicate a tendency towards the application of pesticides with a short time of decomposition. In this way the amount of damage can get reduced. Certain pesticides persist in the soil for a very long time without losing their action. Thus, *e.g.*, DDT, methoxy-chlorine and penta-

chlorophenol persist for 15 years, aldrin, dieldrin, BHC (benzene hexachloride), heptachlor for 9-12 years, toxaphene (camphecor) for 5 years. In spite of certain objections it seems to be proved that the remnants of persistent herbicides have been carried into waters from land either in the form of wind-blown dust and washed-off deposits or without it, in diluted or suspended form. The large-scale fish kill in Lake Balaton, in 1965, was also caused by DDT and γ-BHC (Lindane) (Baron et al. 1967). While these components were hardly detectable in water the organisms serving as food for fishes contained, on the contrary, large amounts of them (Ponyl et al. 1968). Therefore it could be concluded that the accumulation of poisons had occurred along the food chain (algae→invertebrates→non-predatory fish→predatory fish).

Due to the widespread use of pesticides it has been a very complex and difficult task to protect against them. Sufficient protection can be by the sensible choice and application of pesticides though the quantity of chemicals applied should also be reduced. According to Szabo (1973) in 1971, in the catchment of Lake Balaton alone, in large-scale agricultural production 594.3 t of pesticides had been used up. On the basis of preliminary investigations (Czegledi-Janko et al. 1973) it can be concluded that the Lindane pollution of water courses has been widespread in this region. A residue of 2, 4-D could also be detected (Pfeifer et al. 1978).

Synthetic detergents are having large molecular compounds. They exert their action either directly or indirectly. Frequently used detergents are poisonous for a very large number of aquatic organisms. The production and use of synthetic detergents is rapidly increasing, therefore, their danger must be taken into serious consideration. From among other pollutants, mineral oil should be mentioned. The pollution of rivers occurs most frequently.

WATER POLLUTION

The great solvent power of water has been making the creation of absolutely pure water a theoretical rather than a practical goal. Even the highest-quality distilled water is having dissolved gases and

to a slight degree solids. The problem, therefore, has been one of determining what quality of water has been required to meet a given purpose and then finding practical means of achieving that quality. The problem gets further complicated because every use to which water has been put—washing, irrigation, flushing away wastes, cooling, making paper, etc., has been adding something to the water. In fact, for centuries rivers and lakes have been used for dumping grounds for human sewage and industrial wastes of every conceivable kind, many of them have been highly toxic. Added to this have been the materials leached and transported from land by water percolating through the soil and running off its surface to aquatic ecosystems.

The term 'water pollution' is referred to the addition to water of an excess of material (or heat) that is harmful to humans, animals, or desirable aquatic life, or otherwise causes significant departures from the normal activities of various living communities in or near bodies of water. The National Water Commission stated (1973) that "water gets polluted if it has been not of sufficiently high quality to be suitable for the highest uses people wish to make of it at present or in the future."

In reality, the term water pollution refers to any type of aquatic contamination between two extremes : (1) a highly enriched, over productive biotic community, such as a river or lake with nutrients from sewage or fertilizer (**cultural eutrophication**), or (2) a body of water poisoned by toxic chemicals which eleminate living organism or even exclude all forms of life.

The expression "water pollution" seems to be clear to all. Nevertheless, it is worth determining its real meaning as this has changed in the course of time. Felfoldy's (1972) precise definition is the following : "Water pollution is every impact which changes the quality of our surface and subsoil waters to such a degree that its suitability either for human consumption or for the support of man's natural life processes will decrease or cease."

Most of the wastes of civilization are drained into streams and rivers and ultimately into lakes or oceans. In many cases the waste is dumped into the same bodies of water from which drinking water is withdrawn. The effect of sewage, industrial waste, and agricultural drainage on plant and animal life in closed bodies of water is sometimes catastrophic. The accumulation of excessive plant nutrients, called *eutrophication* (which we will consider in detail later in this chapter), has occurred in Lake Erie, Lake Washington at Seattle, the lakes in the Madison, Wisconsin, area, and Lake Zurich in Switzerland.

Coastal waters are also changing due to organic material from sewage outfalls. Marine algae are disappearing from sections of the California coastline. Kelp, an important source of algin used in food and medicines, is diminishing. Heavy metals and pesticide residues are found in fish in amounts above those declared by the Food and Drug Administration to be safe for human consumption. Some species of fish-eating birds accumulate DDT in such large quantities that the pesticide is suspected of being the cause of thin egg shells and the decline of certain species, such as the brown pelican, in some of their breeding grounds. Other species of commercial fish and marine birds are decreasing in numbers at an alarming rate. The specific cause is unknown in most cases.

Water pollution often has been a double problem for industries ; frequently, it has been necessary for the plant to condition the water before its use, as well as to treat the waste water after use. Pretreatment of the water becomes necessary to avoid a number of problems. The following has been a partial list of some of the likely contaminants and the difficulties they are likely to cause.

Alkalinity	: Typically biocarbonates, carbonates, and various caustics.
Problems	: Generates scale, particularly in boilers.
Hardness	: Calcium and magnesium salts primarily. Other salts (for example, iron) are also minor contributors.

Problems	: Scale, particularly in boilers.
Sodium salts	: Often as the sulfates, chlorides, nitrates, and bicarbonates.
Problems	: Very bad for particular industries, such as cellulose and drugs.
Silica (SiO_2)	:
Problems	: Scale.
Iron and manganese	:
Problems	: Tend to stain. Very objectionable in the paper, textile, and tanning industries.
Aluminum	:
Problems	: Usually not a problem for industrial purposes.
Fluorides	:
Problems	: Usually not a problem, except, perhaps in the production of baby foods.
Carbon dioxide	:
Problems	: Increases the alkalinity ; enhances the corrosive behavior of dissolved oxygen.
Oxygen	:
Problems	: Corrosive to iron, steel, galvanized iron, and brass.
Nitrogen	:
Problems	: Helps retain dissolved O_2 in water ; thus increases corrosiveness.
Hydrogen sulfide	:
Problems	: Rotten egg odor ; corosion of iron pipes, fittings, and equipment.
Methane	:
Problems	: Fire and explosion hazard.
Microorganisms	:
Problems	: Form coating in pipes ; stains, tastes, and odors ; decompose organic substances such as cellulose.

Organic matter :
Problems : Causes tastes and odors, often absorbed by various processes ; forms colored colloidal suspensions.

The discharge water from various industries is having many of the same problems, plus some additional ones. The type of contaminant is dependent upon the particular industry and the particular process employed. It is possible to classify the contaminants into three categories :

1. *Floating materials.* Typical floating materials would be oils and greases. They have been making the water unsightly ; retard aquatic plant growth by blocking the sunlight and interfering with the natural reaeration ; destroy the natural vegetation along the banks ; are often toxic to fish and other aquatic life ; destroy water fowl ; and can also be a fire hazard.

2. *Suspended matter.* A common example of suspended matter has been mineral tailings. Typically, mineral tailings form slime and sludge which smother purifying microorganisms and ruin fish spawning and breeding grounds. If the suspended matter has been organic, it would decompose using the dissolved oxygen and would produce noxious gases and odors.

3. *Dissolved impurities.* Typical dissolved substances would be acids, alkalies, heavy metals, and insecticides. In general, they have been making water undrinkable and destroy aquatic life. For example, phenols, even in very low concentrations (0.001 mg/l), provide a very objectionable taste and odor. They also can build and concentrate their effects through the normal food chain. For example, an unpleasant taste is noticed when eating fish which had lived in water with a phenol concentration of only 0.0001 mg/l.

Little is known about the effect on human health of many of the common water pollutants. Nitrates have been linked to methemoglobinemia and death in infants. The ingested nitrates can be reduced by microorganisms in the digestive tract to nitrites :

$NO_3^- \xrightarrow{\text{microorganisms}} NO_2^-$. The nitrites can then oxidize the iron atom present in hemoglobin from Fe^{2+} to Fe^{3+}. The result is a methemoglobin molecule, one which is incapable of O_2 transport.

Most of the other common substances probably have no major acute effects on human health. Many, however, do have chronic effects. For example, many of the organic substances have been reported to be carcinogens. Selenuim causes bad teeth, gastrointestinal problems, and skin discoloration. Sodium and/or potassium are bad for people with certain health problems. On the other hand, some water impurities appear to be beneficial. A deficiency of chromium would favor atherosclerotic diseases ; there is evidence that degenerative cardiovascular disease gets reduced by a factor present in hard water but absent in soft water.

UNPOLLUTED Vs. POLLUTED WATER

Strictly speaking, pollution has been any departure from purity. When environmental pollution has been the topic, the term has come to mean a departure from a normal, rather than from a pure state. This has been particularly true for water. This widely distributed substance has been such a good solvent that it has been never found naturally in a completely pure state.

Even in the most unpolluted geographical areas, rainwater is having dissolved CO_2, O_2, and N_2 and may also carry in suspension dust or other particulates picked up from the atmosphere. Surface and well waters generally contain dissolved compounds of metals like Na, Mg, Ca, and Fe. The term *hard water* is used to describe water that contains appreciable amounts of such compounds. Even drinking water has been not pure in a chemical sense. Suspended solids have been removed and harmful bacteria destroyed, but many substances still remain in solution. Indeed, absolutely pure water would not be pleasant to drink, because it has been is the impurities that impart water the characteristic "taste" by which it is recognized.

In light of the above facts the term *pure*, when used in a water pollution context, will mean a state of water in which no substance

is present in sufficient concentration to prevent the water from being used for purposes thought of as normal. Normal areas of use include :

1. Recreation and aesthetics
2. Public water supply
3. Fish, other aquatic life, and wildlife
4. Agriculture
5. Industry

Any substance that disallows the normal use of water must be regarded as a water pollutant. Part of the complexity of the water pollution problem arises because the normal uses of water are so varied. Water, suited for some uses and therefore considered to be unpolluted, may have to be regarded to be polluted when other uses get contemplated.

PCB's : AN EXAMPLE OF A "COMMON" DISSOLVED TOXIC POLLUTANT

There have been a number of particularly dangerous chemicals which have made their way into our water systems. Many of these chemicals have been in industry effluents, or at least have direct industry sources.

Polychlorinated biphenyls (PCB's) are a well-known example of a toxic substance which has made its way into many of our natural water systems in this manner. PCB-contaminated rice caused an epidemic of a disfiguring skin disease and was blamed for 16 deaths and 2 stillbirths in Japan in 1968. Monsanto, the only U S. company then manufacturing PCB's restricted its sales to only "closed system" electrical applications such as transformers, where they are still used because of their thermal stability, excellent electrical insulating properties, resistance to oxidation, and low biodegradability. They have been still the safest product for this purpose, in terms of fire risk.

In spite of the controls now on PCB's, they are persisting in our environment. Other countries still use them in lubricants, duplicating paper, paints and coatings, adhesives, plastics, and so

forth. The PCB's often leach from landfills, or get into the atmosphere by low-temperature incineration (PCB's do not burn until 2200-2600°F). In addition, industrial spills and other accidents appreciably contribute to the amount in our water systems.

The EPA now requires high-temperature incineration of all PCB liquids drained from transformers and high-and low-voltage capacitors. The transformers, when drained of the PCB's, plus dredge spoils, municipal sewage sludge, and materials contaminated by spills, must also be incinerated or disposed of in a chemical landfill.

The exact health effects of PCB's are now being researched. Laboratory tests have led to liver cancer and reproductive failures in rats, chickens, minks, and rhesus monkeys. People who work with PCB's including employees of many small manufacturers and transformer rebuild shops, have experienced nausea, skin disease, fungus infections, nose and eye irritation, and asthmatic bronchitis.

PCB is being banned in many countries. This ban could be very expensive for many industries if it were immediate and across the board, because of American industry's large capital investment in transformers, and the potential replacement costs.

BOD

A major problem associated with water pollution has been the "biological oxygen demand", or the BOD refers to the amount of oxygen required to biologically oxidize the water contaminants to carbon dioxide (CO_2), and thus is a measure of the suspended, colloidal, or dissolved organics.

The BOD is important in that the higher the BOD, the higher the organic content of the water, and the more dissolved O_2 which will be used to decompose these organics. A lack of dissolved O_2 in the waterways kills off desirable fish (for example, trout). Though there may still be plenty of fish, there usually is a marked change in the types of fish present if the BOD is high.

The presence of organic substances can decrease the dissolved oxygen in another way. The organics, along with the nitrogen and

phosphorous, primarily can serve as food for algae. These algae have been microscopic, greenish-colored plants which live in water. In themselves they are not harmful to humans (in fact, in limited amounts, they are useful, for they do create O_2 for other aquatic life by photosynthesis), but they do become aesthetically unsightly, a nuisance, and a hazard to other aquatic life when they proliferate. Their growth rate has been dependent upon the conditions : they do not grow in deep, fast-moving, muddy, or cold waters, but flourish in lakes, ponds, and slow-moving streams as long as a sufficient supply of nutrients is available. Thus, the nutrients can act as the limiting factor in their growth. Over-fertilization with nutrients, or eutrophication, can take place naturally.

The algae eventually die and decompose. In addition to producing a slimy scum and obnoxious odor, they require O_2 and hence can drastically decrease the dissolved O_2 supply as they decay.

The particular nutrient which has been in limited supply acts as the "limiting factor" in algae growth and multiplication. Usually it has been very difficult, if not impossible, to control the nitrogen. Farm runoff supplies much to the lakes and streams. Some algae have been even nitrogen-fixing, and therefore can obtain all the nitrogen they wish directly from the atmosphere. Organics could be controlled somewhat, but usually the phosphorus is targeted as the nutrient to try to minimize (hence the emphasis on low-phosphorus detergents).

Manufacturing produces large quantities of BOD-20-25 million lb annually. The major contributors have been the chemical industry (about 44% of the manufacturing BOD), the pulp and paper industry (about 27%), and the food processing industries (about 20%).

Table 1.4 lists typical BOD and suspended solids levels produced by a variety of industries.

Related to the BOD, and often measured instead, has been the COD, the chemical oxygen demand. The COD is a measure of the amount of oxygen required to *chemically* oxidize the contaminants

to CO_2. The value of the COD has been higher than the BOD, for strong oxidants are used which force many substances to react which wouldn't react using biological microorganisms. The COD value thus represents almost 100% of the total organics present.

Dissolved sulfites and ferrous compounds, which can act as reducing agents, can also help deplete the O_2 supply.

Table 1.4. Typical Process Waste Strengths

Type of Industry	*Process Wastes (mg/L)*	
	BOD	*Suspended Solids*
Petroleum refining	310	370
Leather and leather products	1300	1700
Flat glass	310	370
Concrete, gypsum, and plastic products	310	10000
Primary metal industries	310	370
Industrial launderers	870	1100
Meat products	800	520
Dairy products	2100	370
Preserved fruits and vegetables	1400	370
Grain mill products	3200	4500
Bakery, mixed	2500	1100
Fast and oils	1300	1100
Malt beverages	2100	980
Malt, wine, brandy, distilled liquor	650	370
Seafood and fish	1400	600
Food preparations	4100	930
Medicinals and botanicals, fermentation	4500	4700
Paints and allied products	2500	600
Industrial organic chemicals	310	370
Miscellaneous chemical products	2500	2600

ACID WATER SYSTEM

Another problem often experienced in natural water systems due to industrial pollutants is a change in the pH of the water.

Natural waters now vary in pH from 4.0 to about 9.5. Some of the acidification of the waters occurs naturally. Carbonic acid, formed by the reaction of CO_2 and water in the atmosphere, is picked up in the normal precipitation process, so that rainwater is typically at about a pH of 5.6. However, acid mine seepage and, particularly, acid rain, have had a major effect on the pH of many lakes and streams. Acid rain, for example, can have a pH as low as 3.9. In areas where calcium or lime are present in the rocks or soil, some of this additional acid is neutralized.

The pH of the water has a major effect on the type of fish and other aquatic species present. A recent study revealed that pH was 30% more important than water temperature and 50% more important than dissolved O_2, at least in the case of bass populations. Both trout and bass prefer alkaline streams, though that may be due somewhat to the additional advantage that more food is usually present. Alkaline streams are usually found in localities where the rock and soil contain $CaCO_3$. Rain, with its normally small amount of carbonic acid (H_2CO_3), dissolves the $CaCO_3$ present and forms calcium bicarbonate. The calcium bicarbonate is a source of CO_2 for photosynthesis by green plants. In addition, the $CaCO_3$ itself is necessary for the growth of crustaceans such as crayfish, scuds, and sow bugs, another source of food for fish. Trout are able to withstand somewhat acidic waters ; in fact, pH values as low as about 5.0 have been possible. However, in these conditions their growth is poor.

This effect on even fairly remote, high-elevation lakes has been a serious problem of particular concern to the sports fisherman. Work is being undertaken by several groups to develop a means of neutralizing some of these acid lakes. It has been experimented with dumping agricultural crushed lime by helicopter into selected lakes, and has found it feasible on a cost/benefit basis. Studies are also underway to develop an acid-resistant strain of brook trout. The situation does not look as if it will improve, however, in the near future.

OTHER CONSIDERATIONS

In general, industrial manufacturing is the leading source of controllable man-made water pollutants. In addition to the large quantities produced, industrial wastes are also much more likely than other types of waste to contain chemicals which are not biodegradable, toxic organic substances, and trace elements which must be removed.

When one considers water pollution control and management, it is necessary to consider, in addition to the nature of the contaminants, also how those substances travel through the water systems. As they travel, the contaminants may be degraded by chemical, physical, or biological processes. They migrate by flow or convection, disperse throughout the water systems by diffusion and/or mixing. In order to make the best decisions as to how to handle these waste waters, it becomes necessary to consider all of these processes and the overall transport. Only in this way can wise decisions be made as to which pollutants must be removed, and which could remain in the effluent. Computer programs have been developed for this purpose, and have been taken advantage of by various industries.

The size of pollutant particles also affects their behavior. The sizes may be categorized as follows :

1. Settleable	$>100\ \mu m$	largely organics
2. Supracolloidal	$1\text{-}100\ \mu m$	largely organics
3. Colloidal	$1\ nm\text{-}1\ \mu m$	bacteria, viruses
4. Soluble	$<1\ nm$	inorganics

The larger particles can be able to absorb and bind various substances on their surfaces, and thus can act as (for example) sites to promote bacterial growth. Clays can absorb dissolved organics such as pesticides. These clays can then settle to the bottom of the lake or stream. In this way, the pesticides and other organics become incorporated into the sediments. The release of these pollutants back into the body of the water has been unclear, and may pose a serious problem in the clean up of our now polluted waters.

The intentional use of soil systems to strain and absorb wastes and to remove even bacteria and viruses has had some limited industrial applications. Often, the soil systems can degrade undesirable compounds to stable ions normally found in ground water—for instance, to nitrates, phosphates, carbonates, and sulfates. On the other hand, sometimes chromate ions, phenols, and many other "toxic" substances have been not degraded, and can migrate underground many miles, contaminating water supplies far from the pollutant source.

THE COSTS OF WATER POLLUTION

The costs of water pollution have been probably even more difficult to estimate than the costs or air pollution. Who can measure the cost of not being able to swim in some river or not being able to catch fish in it ? Who will be able to measure the aesthetic cost of a polluted lake or waterway ? Is it even valid to try to express these costs in monetary terms ?

It is evident that for a very modest price people are able to enjoy a plentiful and generally pure supply of drinking water. The cost has been certainly small in comparison with the cost that would be incurred by society by repetitions of the waterborne epidemics of the recent past.

GANGA ACTION PLAN

The Rs. 560 million Ganga Project that started on a war footing last June has been aimed at settling up sewage treatment plants to tackle 1000 million litres of sewage per day from 27 cities on the bank of river before it being discharged into the river. It would also renovate and augment considerably the capacity of existing sewage pumping stations, construct new pumping stations, and lay additional sewers, Mr. S.S. Bagga, the Divisional Commissioner and Incharge of the project said (The Times of India, July 15,1987). Arrangements are being made to control the discharge of industrial effluents, which are the major sources of pollution besides sewage.

Ganga Action Plan covers 27 cities along the river. The work is going in most of the towns. In Varanasi, under a multi-sectoral city Development Package, ghats are being renovated; sewers are being intercepted and work has been in full swing on two of the three sewage treatment plants. In Kanpur, the sewer network and treatment plants at Jajmau have been part of larger package of development schemes. In Allahabad Gaughat pumping station is being expanded. Nallahs discharging waste into Yamuna river are being intercepted, work is also proceeding fast at the Naini Sewage farm.

The major aspects of the programme have been interception and diversion of sewage now flowing into the river, integrated sewage treatment plants with energy recovery, low cost sanitation, etc.

A wide range of schemes are working to deal with domestic wastes and industrial effluents polluting the river. The Ganga Project Directorate monitors closely all major schemes costing Rs. 50 lakhs or more. State level specialised agencies have been made responsible for execution and maintenance. Many schemes are expected to be completed by the end of the Seventh Plan.

The recovery of resources from the treatment of wastes, monitoring of water quality and conservation of the fish and aquatic life in the river have been important aspects of Ganga Action Plan. All the major universities along the river and scientific organisation under the council of Scientific and Industrial Research and ICAR network have been involved in the formulation of the schemes.

Arrangements are done for regularly monitoring water quality of the river at various locations and at different times. The main thrust of the Ganga Action Plan has been to prevent pollution so that the purity of the river can be restored all along its course.

2

The Hydrologic Cycle

INTRODUCTION

The hydrologic cycle refers to the process whereby water gets converted from its liquid or solid state into its vapor state. As a vapor the water has been capable of travelling considerable distances from its source prior to recondensing and returning to earth as precipitation. Hence the hydrologic cycle has been a complex, interrelated system which is involving the movement of atmospheric, surface (marine and fresh), and groundwater throughout various regions of the world. It has been the hydrologic cycle which has been solely responsible for the world's precipitation, and it is this precipitation, falling on the terrestrial and surface freshwater environments, that has been the sole source of the earth's supply of fresh water (Fig. 2.1).

The hydrologic cycle may be having either a long or various short cycles. In the short cycles, water may evaporate from either marine or freshwater systems, condense almost immediately, and return as precipitation to the same system. Another variation of a short cycle has been the precipitation and subsequent evaporation of water from land surfaces, which has been followed by its condensation and return as precipitation to the land, followed by reevaporation, and so on.

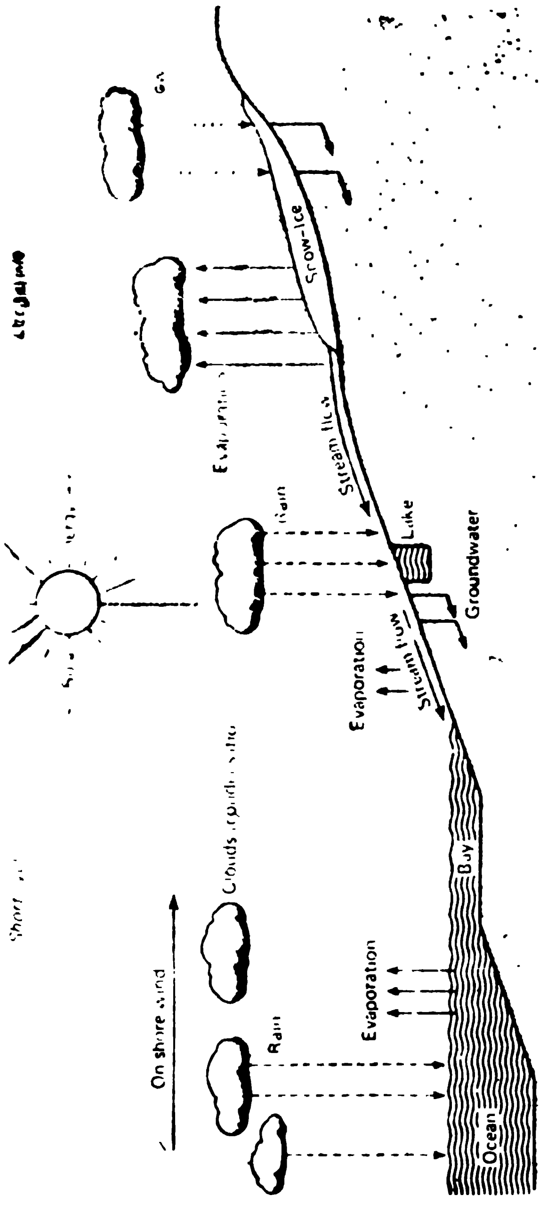


Fig. 2.1. The Hydrologic Cycle

In the long cycle the major source of water vapor has been the world's oceans, which are having 97.3% of the earth's waters. In this cycle a portion of the water evaporates and forms clouds that move inland. The water vapor then cools and returns to earth as precipitation. It is estimated that only 0.007% of the oceanic water has been distributed to terrestrial areas annually. This water will ultimately return to the oceans through river and groundwater flow. As precipitation may take place close to the source of initial evaporation or thousands of miles away, the water may remain in the vapor state for variable times (a few hours to a few weeks). The average residence time for water to remain in the atmosphere is regarded to be 10 days.

STAGES IN THE HYDROLOGIC CYCLE

The various stages in the hydrologic cycle are as follows :

1. Evaporation and Condensation

Water vapor gets evaporated primarily from the oceans and then tends to condense around minute particles, termed *nuclei*, which have been suspended in the atmosphere. The nuclei generally are having small particles of organic material (spores, pollen, etc.), fine mineral particles, volcanic ash, and the like. Dust and smoke particles from industrial sources and automotive exhausts may be serving as nuclei and form a major factor in contributing to the contamination of rainwater. This is due to the fact that airborne partieles (such as lead) readily dissolve in the newly condensed atmospheric water, and these materials then gets returned to earth along with the rainwater.

Initially, the condensed liquid has been in the form of extremely small droplets [less than 0.04 millimeter (mm) in diameter]. Due to their small size, their rate of fall has been negligible, and they get retained in the atmosphere as clouds. Finally, however, this vapor forms precipitation in response to one of three major factors. The largest amount of precipitation would be formed when masses of warm, moist air move into regions of cold air. This causes a rapid condensation of the vapor and subsequent precipitation. The

second factor arises during periods of warm weather, when air, warmed at the earth's surface, gets decreased in density and rises into overlying cold air, bringing about condensation of the water vapor. The third mechanism involved in condensation takes place with the cooling of air masses as they move over high mountains. In each case the cooling of warm, moist air has been responsible for the condensation and precipitation of rainwater.

2. Runoff, Stream Flow, and Infiltration

When rain is falling on a terrestrial area, a portion of the water would be caught by vegetation. This process is known as *interception* and this water readily get reevaporated, as there is a large surface area that is exposed to wind action. The remainder of the water falls to earth, and a portion sinks into the soil surface by a process known as *infiltration*. The portion not infiltrated into the soil, called *surface runoff*, flows over the surface and gets discharged (in undeveloped areas) into streams. The water entering a stream by surface runoff plus the water entering via groundwater flow is known as *runoff*. Thus the terms "runoff" and "surface runoff" have been different and distinct. Surface runoff equals precipitation minus the water lost by interception and infiltration. Runoff, on the other hand, has been generally synonymous with *stream flow* and has been equal to the sum of the surface water plus the groundwater that enters a stream.

Infiltration has been somewhat also distinct from groundwater per se since when the water percolates into the earth's surface, different portions would be following three distinct pathways. A portion of the water will function as interflow, since the presence of impermeable lower sediments will disallow deep penetration of this water. Consequently, this segment will flow just below the soil surface and discharge into streams. Another portion would be remaining above the water table in an area called the *zone of unsaturated flow*. Both of these portions of water are regarded to be in the *zone of aeration*. The third portion will percolate down into the groundwater table and will, eventually, get discharged into streams.

3. Evapotranspiration

A large amount of the precipitated water would be converted to vapor by evaporation and/or transpiration. *Evoporation* refers to the process whereby molecules of liquid water (at the surface of a water body or in moist soil) absorb sufficient energy to leave the liquid state and enter the vapor state. The energy absorbed by the water in this process gets stored within the vapor—hence somewhat large amount of heat contained in the moist air.

Transpiration refers to the process whereby terrestrial and emergent aquatic vegetation release water vapor to the atmosphere. In the process of photosynthesis all plants have been taking in liquid water and carbon dioxide and, by a complex series of reactions, convert these materials to carbohydrate, oxygen (gas), and water vapor. Sub-mergent aquatic vegetation (plants growing completely beneath the water surface) also liberates water and oxygen as vapors but, in these cases, the oxygen and water vapor produced and released into the surrounding liquid water would immediately form hydrogen bonds with the liquid water. The water vapor will get converted to its liquid form, whereas the oxygen remains in the water column as dissolved oxygen. As the leaves of both terrestrial and aquatic emergent vegetation have been in air, the water vapor and oxygen, when released by these plants in photosynthesis, will remain in the vapor state as there are insufficient water molecules in the immediate vicinity to form hydrogen bonds and keep the water vapor and oxygen in solution.

The water converted from liquid to vapor in transpiration has been quite considerable, and the ability of plants to remove water from both soil and aquatic systems cannot be underestimated. Transpiration by emergent vegetation has been a major factor in the "drying up" of lakes.

Groundwater, unless it has been within a few feet of the surface, could not be evaporated. Rather, the portion that gets converted to vapor gets transpired by plants. In most regions the water lost by evaporation cannot be measured separately from the

water lost by transpiration. Consequently, the two are regarded together as *evapotranspiration.*

4. Ground Water

The most lengthy portion of the hydrologic cycle would get completed when groundwater gets returned to the earth's surface. The return may take place by springs, transpiration, or by artificial means.

Any natural surface discharge of sufficient water that will flow as a small rivulet is known as a *spring,* while a smaller discharge is known as *surface seepage.* Groundwater may also be discharged as subaqueous springs below the surface of lakes, rivers, and marine systems. It is possible to classify springs generally on the basis of their magnitude of discharge, as summarized in Table 2.1. Three

Table 2.1. Classification of Spring Discharge

Magnitude	*Discharge*
First	Greater than 2.83 m^3/s
Second	0.283-2.83 m^3/s
Third	2.83-283 litres/s
Fourth	2.83-6.31 litres/s
Fifth	6.31-0.631 litres/s
Sixth	63.1-631 ml/s
Seventh	7.9-63.1 ml/s
Eighth	Less than 7.9 ml/s

major factors affecting the magnitude of a spring have been the land area accepting the rainfall and thus contributing water to the sub-surface system, the permeability of the soil and subsoil, and the quantity of water entering the system (the amount of *recharge*). The use of water, in developed areas, prior to recharge has been known to alter the quality and quantity of the water entering the subsurface systems.

SUMMARY

All the world's waters have been interconnected by the hydrologic cycle. Oceanic water gets evaporated and a portion is carried

as water vapor over terrestrial regions, where it returns to earth as precipitation. This water may then get evaporated or transpired, or it may enter streams, rivers, lakes, or the groundwater system. Regardless of the pathways that the water may take, it has been the sole source of fresh water and, therefore the sole, source of domestic and industrial water. Ultimately, and generally only after use and reuse by man, this water will return to the sea—only to get evaporated and to reenter the hydrologic cycle.

3

Concepts Used in Water Pollution

FOOD CHAIN

The *food chain* may be defined as the transfer of energy (in the form of food) from its source in green plants through a series of "higher" organisms, the animals inhabiting a given system. The energy gets transferred through the food chain by the process of grazing or predation.

We know that the plants have been the original source of the food energy. Therefore, they have been termed as the *producers*, or *autotrophs*. Animals feeding directly upon the plants are known as *herbivores*, or *primary consumers*, while *predators* are termed *secondary*, *tertiary*, etc., *consumers*, depending upon the actual source of their food. A well-managed fish pond will serve to illustrate a typical food chain. In this system the plants, generally phytoplankton (single-celled plants), have been fed upon by the primary consumers, the zooplankton, in turn, serve as a food source for bloodworms, or chironomids, which would occupy the position of secondary consumers. The bloodworms have been the food source of small fish like bluegills (tertiary consumers) and are, in turn, preyed upon by bass (quaternary consumers). Hence the food manufactured by the plants passes from animal to animal and all food chains have been, therefore, dependent on the productivity of the green plants to supply the necessary food to maintain the system.

BIOLOGICAL METHOD OF ZONATION

As sunlight has been such an important factor in the productivity of these systems, it has been customary to divide both marine and freshwater systems into definite zones on the basis of the depth of sunlight penetration. This has been primarily a biological method of zonation. The various wavelengths of light are rapidly filtered out as they pass through a water column. Based upon the degree of light penetration, it has been possible to divide a system into certain zones (Fig. 3.1). The upper zone of sunlight penetration is known as the *euphotic zone*. Beneath this is a zone of perpetual darkness,

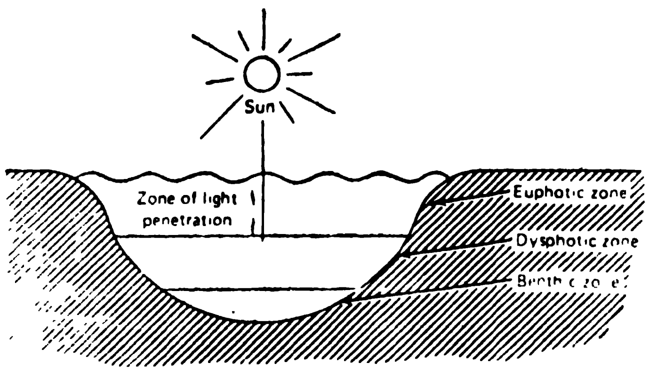


Fig. 3.1. Lake zonation on the basis of sunlight penetration.

the *dysphotic zone*, which is extending from the bottom of the euphotic zone to the bottom. The bottom sediment underlying the dysphotic zone is known as the *benthic zone* or the *regeneration zone*.

According to this type of classification, shallow lakes, streams, and rivers would not behaving a dysphotic zone, as they would be shallow enough to allow for sunlight penetration down to the benthic zone. In addition, the position of both the euphotic and dysphotic zones in deep systems generally shifts with environmental conditions. For example, during periods of heavy rainfall, when sediment has been washed into the system, the physical presence of this suspended sediment would tend to block the sunlight, bringing about a reduction of the euphotic zone and an increase of the dysphotic zone.

In typical aquatic and marine systems the euphotic zone has been regarded to be both the zone of sunlight penetration and the zone of oxygen and food production. It has been in this zone that the plants and the primary consumers would be found, at least during the periods of active photosynthesis and grazing. The other consumers (secondary, tertiary, etc.) would occur in all three zones, depending upon the availability of their food source.

LOTIC ENVIRONMENT

The *lotic environment* is consisting of all inland waters in which the entire water body continually moves in a definite direction. Thus rivers, streams, and brooks are regarded to be lotic environments. These systems have been generally originating from precipitation that falls on the earth's sloping surface and flows downhill as *sheet wash.* Sheet wash tends to accumulate in low areas and to form intermittent rivulets, which eventually flow into streams. When the water flow continues, it will tend to erode the bed of the stream, making it to intercept the groundwater table and become a permanent stream. As additional streams are formed and eventually meet, the resulting length, depth, and size of the system will warrant classification as a river.

The rivulet-stream sequence can still get observed upstream, but in an ever-changing position, because erosion will make an up-stream migration of these features. The migration will continue until halted by a natural feature like a drainage divide. A direct result of this erosion-induced geological migration has been a continual migration of biological habitats. In other words, erosion will make the headwaters to "migrate" upstream which is followed by a similar "migration" of the environmental conditions characteristic of rivulets, streams, and rivers. The animal and plant communities that occupy each of these habitats must also move upstream, to remain in the same habitat (which has been in a constantly changing position because of erosion), or must adapt to the gradually changing conditions brought about by the erosion caused by the running waters. In natural, undisturbed systems these changes have

been very slow and permit ample time for the organism to adapt to the changing conditions.

As lotic systems tend to be shallower and narrower than lakes, there has been generally a greater proportion of water exposed to land surfaces. Consequently, streams have been more intimately associated with and affected by the terrestrial environment than have been most lentic systems. In addition, lotic systems have been more dependent on the surrounding land areas for a large proportion of their nutrient supply.

LENTIC ENVIRONMENT

The *lentic environment* has been including all inland waters in which the water has been not continually flowing in a definite direction. The water in these systems has been essentially standing, although some water motion may take place because of wind-driven waves and/or in the vicinity of inlets and outlets. From a long-term geologic viewpoint, however, these inlets and outlets have been regarded to be temporary impoundments that will in time disappear, converting the system to a flowing-water environment. Typical lentic environments have been regarded to be lakes, ponds, and marshes.

In lentic systems the aging process has been just the reverse of that described for lotic systems. Whereas streams tend to get wider and deeper as they age, lakes tend to get shallower and the banks extend into what was originally open water. Natural filling has been generally due to wind-blown materials (sand, leaves, etc.) entering the system, sediment input by streams, and terrestrial runoff and aquatic plant and animal debris. Not all lentic environments have been becoming shallower by this type of filling alone, however. In many cases outlets may widen and deepen, making an increased outflow of water having a subsequent lowering of the water level.

Lakes could be generally classified, on the basis of their depth and nutrient levels, as *oligotrophic*, *eutrophic*, or *senescent*.

An *oligotrophic lake* has been regarded to be in its young stage. These lakes have been very deep, with a sand or rock bottom, and

have been low in nutrients. Because of the paucity of nutrients, both plant and animal life are low.

Eutrophic lakes have been regarded as middle-aged systems. They have been relatively shallow in comparison to oligotrophic systems, with a silty or mud bottom, and have sufficient nutrients for supporting a large population of plants and animals.

A *senescent lake* has been in the oldest stage of development. The bottom sediments in senescent systems have been consisting of a thick layer of organic silts and/or muds, nutrient levels are high, and the system has been very shallow. There has been a large percentage of rooted emergent vegetation which is growing throughout the system. Terrestrial or marsh vegetation tends to grow along the banks and into the lake itself over the root mat.

On the basis of temperature (and thus, indirectly, density) lakes could be divided into three distinct zones : the *epilimnion*, the *thermocline*, and the *hypolimnion* (Fig. 3.2). The *epilimnion* has been the upper zone of gradual temperature change. Below the epilimnion has been a zone of rapid temperature change, termed the *thermocline*. In order for this region to meet the established criterion for classification as a thermocline, the temperature must alter by at least 1°C for every metre of depth. If the temperature changes at a lesser rate relative to depth, these waters would be classified as a portion of the

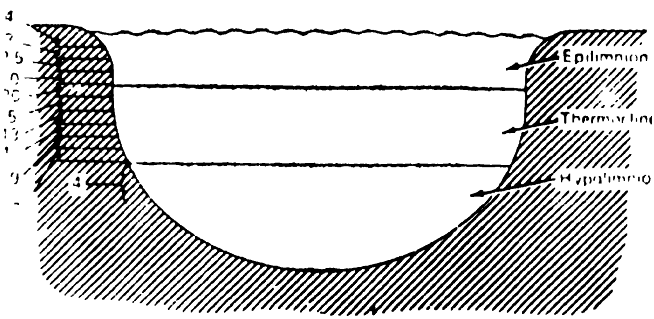


Fig. 3.2. Typical lake stratification—summer.

epilimnion. Below the thermocline there has been an area of water that has been constantly at a temperature of 4°C, termed the

hypolimnion. As the waters of the hypolimnion have been at 4°C they have been at their maximum density and will occur at the bottom layer in any system. Comparing the relative water temperatures and density variations seasonally, it has been noted that in summer the warmer water will get located in the upper epilimnion and the colder, denser, water will be located in the hypolimnion. In the winter the colder, less dense water at temperatures below 4°C will be located in the hypolimnion. In either case, the less dense water has been in the epilimnion and the dense (4°C) water has been always found in the bottom waters of the hypolimnion.

During stagnation periods two simultaneous events take place : nutrient depletion in the epilimnion and oxygen depletion in the hypolimnion. Throughout the summer death of the plants and death and excretion of the unimals will continue to add organic material to the regeneration zone that underlies the hypolimnion. The bacteria inhabiting the bottom sediment will continue to break this organic material down and convert it into inorganic phosphate and nitrate, which has been the proper form for utilization by plants confined to the eupnotic zone. The inorganic phosphate and nitrate will go into solution readily in the waters of the hypolimnion. However, as the lake has been stratified, the temperature-density barrier formed by the thermocline disallows these nutrients from reaching the euphotic zone. Hence the nitrate and phosphate are in the proper form for use by the plants, but it is in the wrong place—the hypolimnion. When this takes place the nutrients are considered to be spatially unavailable. During a prolonged stagnation these nutrients will build up to large concentrations in the hypolimnion, causing a nutrient depletion in the epilimnion. At these times large numbers of plants, with no source of nutrients to carry on their metabolic processes, would die. If this takes place the animal component of the system, dependent on the plants for the conversion of nutrients into the organic form as well as for the production of oxygen, will also get eliminated.

As the summer comes to a close, a combination of cooler atmospheric temperatures and increased wind action makes the

surface waters of the epilimnion to mix slightly. As cooling takes place at the surface, these waters become colder and denser. Eventually the surface waters get colder and denser than the deeper waters. When this takes place as they are denser, they will sink to a depth of equal density. This exposes subsurface waters to atmospheric conditions, and these waters will start to cool, increase in density, and then sink to a depth of equal density. Through this process the entire epilimnion eventually becomes uniform in temperature (homothermous). As the fall temperatures become colder, the epilimnion, by the same process of water cooling, increasing in density and sinking, mixes with the thermocline. In mid-to late fall the entire lake has been becoming homothermous at 4°C, and there has been a complete mixing of water from top to bottom. This is called the *fall overturn.* At this time inorganic nutrients that get accumulated in the hypolimnion throughout the summer stagnation get returned to the euphotic portion of the epilimnion and become available to the plants. Consequently, the fall overturn is marked by large plankton blooms. As there has been abundant plant life in the lake at this point, there has been a corresponding increase in the animal life.

Also during the fall overturn, because of the mixing of the entire water column, oxygen-rich water from the epilimnion has been circulated down to the thermocline and the hypolimnion. This allows the more efficient aerobic decomposition to take place. During the overturn periods life in the lake gets renewed, and the lake has been said to "turn over and breathe".

The fall overturn has been followed by the winter stagnation period. When atmospheric temperatures continue to cool, a point would be reached where the surface waters of the lake (the temperature of the lake prior to the onset of winter stagnation has been homothermous at 4°C) start to cool below 4°C. As cooling takes place. the waters become less dense. Consequently, the cooler, less-dense surface water tends to remain in place, overlying the denser subsurface water still at 4°C. Eventually a point has been reached where the surface waters have been cooled sufficiently so that they

form a definite epilimnion, which has been prevented from effectively mixing with the bottom hypolimnion by the temperature-density barrier of the thermocline. Hence in winter stagnation the cooler, less-dense water has been located at the surface and the dense (4°C) warmer water is located in the hypolimnion. This is the reverse of the temperature distribution during summer stagnation ; in either case, however, the dense 4°C water gets located in the hypolimnion and the less dense (warmer in summer, cooler in winter) water gets located in the epilimnion. Althongh wind action has been considerable in winter, the ice cover of the surface-water layer disallows wind mixing and subsequent disruption of the water stratification. It is to be noted, however, that with the smaller temperature variation between the epilimnion and the hypolimnion in winter, the thermocline has been not as well established or of as great a volume as during the summer stagnation. The same chemical and biological changes take place during the winter stagnation as have been noted for the summer stagnation.

Predictably, the winter stagnation has been followed by the sprin; overturn. It would be brought about by atmospheric temperatures which melt the ice cover and expose the surface waters to wind action and solar heating. As the surface water warms up (above 0°C), the density of the water increases, making the newly warmed surface water to sink to a depth of equal density. It will expose subsurface water to the atmosphere, and this newly exposed water will get warmed, increase in density, and sink. Eventually, by this repeated process of warming and sinking, combined with wind mixing, the entire lake will become homothermous at 4°C, mix from top to bottom, and enter the spring overturn. During this period, as in the fall overturn, nutrients have been brought to the surface and oxygen to the hypolimnion.

As the summer period gets entered, the increased atmospheric temperatures would warm the surface waters above 4°C. This warming cusing the water decreasing in density and again forming layers above the denser, subsurface water. Eventually, the surface water will warm to such an extent that the surface epilimnion will be

effectively prevented from mixing with the hypolimnion by the temperature-density barrier of the thermocline. The lake, at this time, will again be in its summer stagnation period.

A lake could be classified as *oligotrophic*, *eutrophic*, or *senescent*, depending on its depth, nutrient levels, and biological composition. The normal sequence has been for an oligotrophic lake to age gradually to its eutrophic stage and then to its senescent stage. This aging takes place two simultaneous processes : filling with terrestrial and aquatic debris ; and cutting down of the outlet stream bed, making a greater volume of water to flow out. Both processes give rise to a lowering of the lake surface. Determining the age of a lake has been rather inexact, as there has been a large variation in the physical and biological characteristics of lentic systems. In general, a eutrophic stage would get reached when the nutrients have been at a suitable level to support a large population of plant and animal communities and the hypolimnion is consistently smaller than the epilimnion. As a lake ages, the plankton populations generally tend to increase, owing to an increase in nutrient levels. As the filling continues, a stage has been eventually reached where the thermocline never develops and complete vertical circulation takes place throughout the year. Consequently, the lake will tend to warm above 4°C, and cold-water forms such as trout will be eliminated. The lake at this stage has been classified as senescent. It has been in this stage that the water levels have been so shallow that rooted plants get established in even the deepest part of the lake. Eventually, via normal filling, the senescent stage is passed and the system may become a pond (merely a smaller, shallower area of permanent or temporary open water), or it may develop immediately into a swamp or marsh. (By definition a swamp contains water-loving or hydric trees, whereas a marsh is treeless). It has to be noted, however, that all ponds and marshes were not, at one time, oligotropic lakes. In many cases these areas were never deep enough to be considered oligotrophic. In these instances they started as eutrophic or senescent systems or as ponds. It has also to be noted that as any of these areas age and become shallower, environmental changes are of greater consequence, as there has been less water volume to compen-

sate for and dilute the influx of these materials. For example, the input of large amounts of organic material into an oligotrophic lake would be less harmful than the input of the same type and amount of material into a shallow, senescent lake or pond.

SOIL ZONATION

A portion of the water entering the ground will get trapped by rock, soil, and so on, and remain in the upper soil zone (Fig. 3.3) as suspended water. Suspended water has been disallowed from moving deeper into the soil by the molecular attractions that are exerted on the water by the surrounding soil particles, as well as by the intermolecular attractions exerted by water molecules on each other. As the spaces between the soil particles in this zone have been filled with a mixture of air and water, this portion of the soil has been known as the *zone of aeration* and has been subdivided into three distinct horizons: the horizon of soil moisture, the intermediate horizon (which may or may not be present), and the capillary fringe.

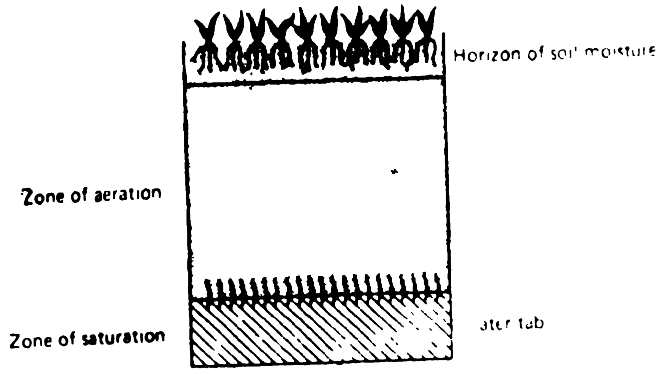


Fig. 3.3. Soil zonation.

A portion of the water that enters the horizon of soil moisture could be either evaporated or transpired. The remainder would be passing into the intermediote horizon, where it tends to be held as suspended water by molecular attractions. There occurs little water movement in the intermediate horizon, except during periods of precipitation, when additional incoming water enters this horizon.

In some areas the intermediate horizon has been absent, and the horizon of soil moisture lies directly over the third horizon - the *capillary fringe.* Water moves into the capillary fringe (by capillary action) from below.

The zone of saturation has been lying below the zone of aeration (Fig. 3.3). In this zone there has been no trapped air and the openings in the soil have been completely saturated with groundwater. The boundary between the zone of saturation has been termed the *water table.* which may be defined as that point where subsurface water will flow into a well under the force of gravity. The amount, degree of motion, and depth of groundwater has been controlled by the structure of the soil and subsoil. Most soils and subsoils have been composed of rock and rock fragments that vary in size, density, and compaction. The particles may be small and regular in shape, which results in a close intergranular "fit" with little pore space between the particles. Because of the low degree of pore space, these subsoils cannot hold much water between the particles and have been said to be of *low permeability.* In other words, subsoils of this nature are having little ability to hold or transmit fluids. An example of such a subsoil is clay (Fig. 3.4A). Other subsoils may consist of large, irregularly shaped particles that fit together poorly. This type of structure causes many small, inter-

Fig 3.4. Typical pore spacing in clay and gravel.

connecting pore spaces into which water may flow and move. Subsoil of this type is having a high ability to hold and transmit fluids and is said to be *permeable.* Subsoils of gravel or sand (Fig. 3.4B)

have been highly permeable materials. A recognizable portion of the subsoil that permeable and through which water moves has been termed an *aquifer.*

The zone of saturation could be formed by water moving through the subsoil under the influence of gravity and eventually encountering a barrier that disallows further water movement. The barrier may be the result of the water encountering materials of low permeability, a dense, compact mass such as igneous rock, or some other barrier impervious to water movement. Water that encounters such a barrier, termed an *aqualard*, tends to completely fill the pore spaces in the aquifer. When this takes place the pore spaces become saturated and a zone of saturation gets formed. The upper surface of this zone, the water table, therefore represents the upper limit to the usable groundwater.

In most cases the water table has been located only a few metres below the surface. It may, however, be at the surface, as at the shores of rivers, streams, or some lakes. In other cases it may be at great depths, as in desert areas. Hence, the quantity of groundwater would vary geographically in relation to climate and soil conditions. For example, along the Coastal Plain of the United States (a belt of low-lying land along the Atlantic and Gulf Coast), large quantities of groundwater occur in sand, gravel, limestone, and sandstone deposits and provide extensive reservoirs of water. Throughout the Great Plains and the Western and Mountain States, groundwater has been much less abundant.

GROUNDWATER QUALITY

Groundwater has been always free of suspended materials because the sediments that comprise the aquifer serve as filters and effectively remove all particulate matter. These sediments do not, however, remove many of the dissolved materials from the water ; as water has been regarded to be the universal solvent, it can be expected to have a high concentration of dissolved materials. For example, particles relased as smoke from industrial processes may act as nuclei around which water vapor can condense. When this

take place these particles will dissolve in the newly condensed water and will get returned to earth in their dissolved form. Upon returning to earth, they may be carried into surface-water bodies as runoff or into the aquifer with the groundwater, So, in this case, the quality of the groundwater has been dependent on the quality of the air through which the water vapor travelled. Another type of material that may enter groundwater has been comprised of inorganic plant nutrients that enter from cess-pool and septic-tank recharge or because of the fertilization of lawns and agricultural lands.

Once materials get dissolved in the water percolate into the soil, they leave the euphotic zone. Hence, in aquifers there has been a total absence of vegetation and, therefore, no food chain as such. Certain types of bacteria may be able to survive in these areas by using organic materials that are carried in from the surface and by converting these materials into their inorganic forms (c-PO_4 and NO_3), which will increase the concentrations of these materials. In the absence of plants, however, these materials cannot be used. Hence, the aquifer will act as a reservoir of spatially unavailable plant nutrients and other dissolved materials.

4

Water Quality

INTRODUCTION

To introduce the environmental reader to some of the desired objectives in controlling water pollutants, some of the water quality criteria used in different countries are present here. Water quality objectives guarantee a healthy populace and high rate of industrialisation.

QUALITY OF WATER FOR DRINKING

Supplies have to be drawn from the best available source. When the source cannot be protected against pollution the water has to be treated to easure its safety. Possible hazards must be known by sanitary surveys and eliminated.

BACTERIOLOGICAL QUALITY

The coliform index may be regarded as a measure of the concentration of coliform organism or E-Coli in a water sample. It may be defined as the reciprocal of the smallest quantity of sample (in ml) which would undergo a positive E-coli test. This index is almost obsolete. Now Most Probable Number (MPN) has been commonly used. MPN may be defined as that bacterial density which if it had been actually present in the sample under examination, would more frequently than another, have give the observed analytical result.

There has been however, a slight difference in the interpretation of the significance of actual numbers of coliforms indicated in each 100 millilitre (ml) portion. None of the samples having coliform organisms must have an MPN index greater than 10 per 100 ml, while in the MF technique none of the coliform counts must be greater than 4 per 100 ml. If samples of water approach or exceed these limits in consecutive examinations, then an immediate investigation should get initiated to locate and eliminate the source of the contamination. At the same time a series of "special samples" have been needed to determine the extent of contamination and the progress being made toward its elimination from the water supply. This special sampling continues until the bacteriological water quality has been proved to be satisfactory. "Special samples" have been also required when more than 10% of the samples collected per month and tested by either the MPN of MF methods reveal the presence of coliform organisms.

There is another method of analysis which involves running a series of confirmation tests to confirm and definitely establish the presence or absence of a vatiety of pollution indicator bacteria. These specialized tests have been needed to identify pathogenic cultures as to genus and species.

Frequency of Sampling

Contamination has been generally intermittent and cannot be revealated by the examination of a single sample. The examination of a single sample can reveal no more than the conditions prevailing at the time of sampling ; a satisfactory result fails to guarantee that the observed conditions will prevail in the future. A series of samples over a period of time has been thus needed.

In order to ensure reliable results, samples must arrive at the testing laboratory within 24 hr of sampling or be refrigerated if delay has been unavoidable. The sample must be collected directly into sterile bottles and not via a dipper or some other container. It must be stressed that the reliability of the results has been wholly dependent upon the employment of proper sampling techniques and the

care with which the samples are collected. The minimum number of samples required from specific sources have been shown in Table 4.1.

Table 4.1. Sampling Frequency.

Description of source	*No. of Samples*	*Minimum frequency of sampling*
Treated surface water	1 raw and 1 treated at plant	Once per week
Treated ground water	1 raw and 1 treated from each source	Twice per week
Untreated ground water	1 raw from each source and 1 from each point of entry into the distribution system	Once per week

The minimum number of samples to be collected and the frequency of sample collection from a distribution system have been generally based on the size of the population served (Table 4.2).

Table 4.2. Sample Frequency based on Pollution.

Population served	*Minimum number of samples per month*	*Minimum frequency of sampling intervals*
Up to 1,000	2	Twice per week
1,001-100,000	10+1 per 1000 of population per month	Once per week
Over 100,000	100+1 per 10,000 of population per month	Once per day

The number of samples determined with the use of the above table must not include plant effluents whether treated or otherwise.

As a typical example we will consider a municipality of 2400 persons having two wells providing treated ground water to the system. Bacteriological sampling would be considering of the submission twice per month of a raw water sample from each of the sources of supply and a treated water sample from each of the points of discharge to the distribution system. In addition, a total of 12 bacteriological samples per month would have to be taken from various points in the distribution system. This would entail the submission of three samples per week so as to meet the sampling frequency requirement.

The responsibility for taking the required number of samples has been lying with the operating authority, whether it be a municipality or an individual who owns a private water supply. The total number of samples to be collected monthly may be examined by the laboratories. "Special samples" have been not included in the total number of samples needed above.

PHYSICAL CHARACTERISTICS

The physical characteristics of water must be analysed of at least once a week. Samples are drawn from representative points through out.

Physical tests do not directly measure the safety of a water supply ; however, they do give an indication of its acceptability. Thus, objectives governing the physical characteristics of the water have been somewhat less stringent than those needed for bacteriological control. The physical qualities of concern have been turbidity, color, taste and odor, temperature and pH. [Except for temperature and pH, these results may be reported in parts per million, ppm (Table 4.3).] However, oftentimes other units have become established and accepted in practice.

Table 4.3. Physical Quality of Treated Water.

Parameter	*Objective*	*Acceptable Limit*
Color, TCU	<5	15
Odor, TON	0	4
Taste	Inoffensive	Inoffensive
Turbidity, JTU	<1	5
Temperature, °C	<10	15
pH	——	6.5-8.3

(*a*) **Turbidity**

Turbidity should average not more than 1 (turbidity) unit, although and Jackson turbidity unit of 5 has been acceptable. At levels approaching 10 units the water may appear cloudy to the observer. Plants that provide complete treatment must routinely produce water than meets this objective. Ground water supplies will normally meet the objective without the need for treatment.

(*b*) **Colour**

Color must average not more than 5 (apparent color) units. Color does not take place too frequently in the natural waters. Leaching effect of the water on organic material found in certain watersheds may range beyond 50 units. Removal has been possible with alum coagulation, sedimentation, and filteration.

(*c*) **Temperature**

Temperature has been a physical characteristics about which little can be done. The most desirable range has been from 40-50°F (4-10°C). Higher temperatures tend to make water less palatable and decease its suitability for air conditioning purpose. Temperatures above 80°F (27°C) have been unsuitable and above 90°F (32°C) have besn unfit for public use.

CHEMICAL CHARACTERISTICS

Drinking water should not be having impurities in hazardous concentrations.

Under normal circumstances, analyses for chemical constituents must only be made semiannually. If, however, the supply has been suspected of having undesirable elements, compounds, or materials, then periodic determinations for the suspected toxicant or material must be done at more frequent intervals. Where experience reveals that particular substances have been consistently absent from a water supply, semiannual examinations for these substances might be omitted on government approval.

(*a*) Limits for Chemical Constituents

The chemical constituent concentrations in water could be broken down into two categories : those concentrations that can be tolerated if another, more suitable source has been not available, and those concentrations that constitute grounds for rejection. Due to the rapidly changing field of complex chemicals, it has become important that the objectives for chemical constituents must be reviewed regularly.

(*b*) Taste and Colour

Taste and odor have been very closely related and have been caused by the same conditions. A good objective for odor has been a threshold odor number (TON) not greater than 3 and the tasts should not be objectionable. Common sources of taste and odor have been as follows :

1. *Dead or decaying organic matter.*
2. *Living organisms and oils from algae.*
3. *Industrial wastes* (phenolic wastes may produce a medicinal tests and odor at concentrations as low as 1 ppb when contacted by chlorine).
4. *Dissolved gases* (hydrogen sulfide, methane, etc.).
5. *Dissolved minerals* (chlorides, sulphates, and metallic salts, such as copper and iron).

The physical characteristics give only part of the picture of water quality. They have been however, very important when related to surfaee waters of variable quality. Normally, ground water

will meet all physical requirements, but occasionally the taste and odor of a well or spring supply would be significant. The presence of hydrogen sulfide gas in a well supply in any amount would generally discourage its use. Algae blooms produce off-flavors, which have been becoming a greater nuisance as lake waters are being used more frequently in potable water production.

Consumer acceptance has been an exellcent guide as to whether taste and odor criteria are being met.

Chemical standards for acceptable water have been scrutinized for over 50 years. In other communities and water plants, semi-annual examination often suffices to establish whether objectives are being met. Frequency of examination has been often set by regulatory agencies.

Assays for common toxic chemicals must get completed. Common toxicants have been arsenic, barium, boron, cadmium, chromium, cyanide, lead, nitrate (nitrite), selenium and silver.

Many synthetic and highly toxic biocides have been produced and find their way into raw water. A 24-hr composite sample of raw water must be collected and examined at least once every three months for the common biocides. These have been aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, heptachlor epoxide, lindane, methoxychlor, organic phosphates+carbamates, toxaphene, and herbicides such as 2, 4-D, 2, 4, 5-T and 2, 4, 5-TP. Choline esterase inhibition has been used to determine toxic biocide levels.

(c) Problems Associated with Chemical Constituents

1. Alkyl Benezene Sulfonate (ABS)

Contamination of drinking water supplies with ABS results from its disposal as a detergent in household and industrial wastes. The concentration of ABS in municipal sewage has been found to range as high as 10 ppm. Linear alkylsulphates (LAS) which have replaced many ABS compounds occur at the same level. Such contamination may appear in both surface and ground water supplies. The objective for either ABS or LAS in water supplies has

been set at 0.5 ppm (mg/litre). Tests have confirmed that 1 ppm presents an off-taste to water. This level often brings about foaming. No apparent toxic effects have been evident with water having 50 ppm of ABS. Linear alkylsulfonates must be handled in a manner similar to ABS compounds until specific control levels have been established.

2. **Arsenic** (AS)

The widespread use of inorganic arsenic in insecticides has caused its presence in animal foods, tobacco, and other sources. This makes it necessary to set a limit on the concentration of this chemical in drinking water. Our present knowledge concerning the potential health hazards associated with the ingestion of organic arsenic reveals that the concentration of arsenic in drinking water must not exceed 0.01 ppm and concentrations in excess of 0.05 ppm mg/litre) are grounds for rejection.

3. **Barium** (Ba)

Bariam has been not a common contaminant of water. An excess of 1.0 ppm has been grounds for rejection due to the seriousness of the toxic effects of barium on the heart function, blood vessels, and nerves.

4. **Boron** (B)

Boron gets rapidly absorbed by the human intestine and gets excreted in the urine. Ingestion of large amounts affects the central nervous system. Protracted ingestion results in a clinical syndrome referred to as "boroism."

5. **Cadmium** (Cd)

Cadmium is having high toxic potential. Very little attention has been paid to this constituent.

Seepage of cadmium into ground water from electroplating plants has resulted in concentrations up to 3.2 ppm. Other sources of cadmium contamination in water have been arising from zinc-galvanized iron in which cadmium has been used. Tests have shown that concentrations up to 0.01 ppm can be tolerated but con-

centrations in excess of this have been regarded grounds for rejecting a water supply.

6. **Carbon Chloroform Extract** (CCE)

The carbon chloroform extract (CCE) test has been a practical measure of water quality and has been a safeguard against the intrusion of excessive amounts of potentially toxic material into water. It has been proposed as a technically practical procedure that provides a measure of protection against the presence of undetected toxic materials.

The test has been an indication of organic material in the treated water, the presence of which shows that pollutants have not been removed in the treatment process. The objective for CCE has been 0.2 ppm.

7. **Chloride (Cl)**

The objective for chloride has been set at an upper limit of 250 ppm. Above this level a salty taste has been apparent. Many municipalities experience higher levels of chloride with varying taste intensities. Abnormal amounts of chloride in a natural water postulate pollution probably of a chemical origin.

8. **Chromium (Cr^{6+})**

Chromium has been another unnatural constituent of water supplies and has been not known to be either an essential or beneficial element in the body. Its presence has been indicative of industrial pollution which has been probably caused by a plating or tannery operation. Concentration in excess of 0.05 ppm as hexavalent chromium (Cr^{6+}) has been grounds for rejection. Trivalent chromium has been not believed to be toxic.

9. **Copper (Cu)**

Copper has been an essential and beneficial element in human metabolism. A deficiency in copper give rise to nutritional problems in infants. Copper imparts some taste to water and has been detectable in ranges from 1 to 5 ppm. Small amounts are not generally considered as toxic, but very large doses may causes sickness and in

extreme cases liver damage. In the use of copper sulphate in a surface water supply for algal control, the levels have to be closely controlled.

Copper in small amounts does not constitute a health hazard but imparts an undesirable taste to drinking water.

10. **Cyanide (CN)**

As proper treatment of water will reduce cyanide levels to less than 0 01 ppm, this objective is usually adopted. For the protection of health, concentrations above 0.2 ppm constitute grounds for rejection. A substantial safety factor has been provided at the 0.01 ppm concentration due to the rapidly fatal effect of this chemical.

11. **Fluoride (F)**

Fluoride in drinking water disallows dental caries in children and to a lesser degree in young adults. Where the addition of fluoride to the water supply has been practiced, a 1.0 ppm concentration has been recommended, with a permissible operating range of 0.8—1.2 ppm. It is believed that mottling of the teeth or enamel fluorosis takes place concentrations above 1.2 ppm. When fluoride has been naturally present, the concentration must not average more than 1.2 ppm. Presence of fluoride in concentrations more than 1.5 ppm should be rejected. In the arctic and subarctic areas fluoride must be maintained at 1.4 ppm.

12. **Iron (Fe)**

Iron has been regarded at times a highly objectionable constituent in water for either domestic or industrial supplies. The domestic consumer complains of the brownish color that iron has been imparting to plumbing fixture and laundered goods. Iron also affects the taste of beverages. The upper limit for iron has been 0.3 ppm, with the overall objective being set at 0.05 mg/liter. Water mains could become fouled by the masses of stringy growths associated with iron oxidizing microbes. Associated with iron has been the corrosion and encrustation problem.

13. **Lead (Pb)**

Lead taken into the body may be seriously injurious to health or even lethal. Lead must not exceed 0.05 ppm. Constructions in excess of this amount have been grounds for rejection.

14. **Methylene Blue Active Substances (MBAS)**

This determination reveals the presence of synthetic detergents, foaming, excessive turbidity, odor containing substances, etc. The effectiveness of chlorine disinfection decreases if the MBAS has been over 4.0 mg/litre of ABS-equivalent. A concentration of MBAS above 0.5 mg/litre as ABS-equivalent has been indicative of other wastewater pollution.

15. **Urany Ion**

Uranyl ions are known to produce damage to kidneys. The threshold limit for taste has been 10 mg/litre as UO_2, which has been less than the safe limit for ingestion. The maximum permissible limit has been 5.0 mg/litre, based on color and taste considerations.

16. **Managanese (Mn)**

Manganese presents much the same nuisance conditions as iron. It has been difficult to remove this chemical and it has been recommended that concentrations not exceed 0.05 ppm.

17. **Nitrate (NO_3) and Nitrites (NO_2)**

Serious and occasionally fatal poisonings of infants have taken place following ingestion of well waters shown to high levels of nitrate. Wastes from chemical fertilizer plants and field fertilization run-off have been sources of such pollution.

Nitrate poisoning has been confined to infants during their first few months of life. Nitrates bring about infantile methemoglobinemia ("blue-baby" condition). It can be cured or terminated by providing nitrate-free water. Nitrates bring about irritation of the mucuous membrances of the stomach in adults and increased diuresis.

Several authorities have adopted the objective of <10.0 ppm nitrate as NO_3 with an upper acceptable limit of 45.0 ppm. In areas

where the nitrate content of water is known to be in excess of the listed concentration, the public must be warned of the potential dangers of using the water for infant feeding.

18. **Phenol**

Undesirable tastes often result from the chlorination of waters having extremely low concentrations of phenol. The objective for phenol has been 2 ppb (0.002 ppm).

19. **Selenium (Se)**

Levels of selenium in excess of 0.01 ppm constitute grounds for rejection of a water supply. Trace amounts of this chemical have been essential to man, while higher concentrations appear to be extremely toxic in a manner similar to arsenic. Surveys have also shown that selenium tends to increase the rate of dental caries in permanent teeth.

20. **Silver (Ag)**

A water supply must be rejected if it is having more than 0.05 ppm of silver. This level has been established, not because of toxic effects, but due to the unsightly, permanent blue-grey discoloration of the skin, eyes, and mucuous membranes which results from its ingestion. Evidence reveals that silver, ones absorbed, has been bound indefinitely in the tissues, particularly the skin.

21. **Sulfate (SO_4)**

A diarrhea effect has been commonly noted by newcomers and casual users of waters high in sulfates. Persons adapt to these waters in relatively short time periods. The taste of the water has been adversely affected at the upper limit, recommended as 250 ppm.

22. **Total Dissolved Solids**

High dissolved-solids concentrations have been associated with correspondingly high levels of sulfates and/or chlorides. An upper limit of 500 ppm has been set so as to control undesirable taste and diarrhea.

23. **Zinc (Zn)**

Zinc has been an essential and beneficial element in human metabolism and does not appear to have a serious effect on health. Zinc salts are having a tendency to impart a milky appearance to water at 30 ppm and a metallic taste about 40 ppm. These have been the only apparent undesirable characteristics. An objective of 5 0 ppm has been acceptable.

(*d*) **Miscellaneous Chemical Considerations**

In addition to the purely chemical characteristics that should be regarded there have been other characteristics, which for want of a better term, could be classified as miscellaneous.

1. **Acidity and Alkalinity**

Alkalinity and acidity of water refer to the amounts of acids or bases present and may be measured in ppm. These should not get confused with pH, which has been a measure of the hydrogen ion concentration measured on an arbitrary scale from 0 to 14. There have been no particular limits for either alkalinity or acidity and both have been expressed in terms of $CaCO_3$. Highly acid or alkaline waters must be avoided and could be dangerous.

Acidity has been not desirable in a municipal water system primarily because it tends to increase corrosion.

Alkalinity refers to the carbonate, bicarbonate, and hydroxide content of a water and commonly occur in the form of a carbonate of soda (Na) and as bicarbonates of calcium (Ca) and magnesium (Mg). Where the alkalinity exceeds the hardness, the presence of basic salts, generally sodium (Na) and pottasium (K), has been indicated. If the alkalinity has been less than the hardness then salt of Ca^{2+} and Mg^{2+} would be present in association with sulfates, chlorides, or nitrates. Grains of hardness for drinking water must be maintained between 4.7 and 7.0, or less than 81-120 mg/litre of $CaCO_3$. Very good waters are having less than 80 mg/litre of $CaCO_3$.

2. Carbon Dioxide

In surface supplies the normal CO_2 content would range from 0.5 to 2.0 ppm, while in ground water it would range as high as 50 ppm. A proper balance of carbon dioxide in water will ensure that the water has been neither corrosive nor scale-forming.

3. Hardness

Water has been found to range from less than 10 ppm to 1800 ppm. A preferable hardness must be in the range 90-100 ppm. Above 500 ppm the water may be regarded objectionable for domestic use. Waters with hardness less than 30 ppm have been quite soft and usually not corrosive.

4. Hodrogen Sulfide

Even trace amounts of hydrogen sulfide (H_2S) will impart a taste and odor characteristic. It has been not harmful from a health standpoint at levels that persons would consider for drinking.

5. pH

Natural waters generally have been found to range from pH 5.5 to 8.6. Waters with lower pH tend to bring about corrosion, and in many cases an unward adjustment to the neutral range (pH 7.0) has been necessary. Drinking water with a pH range from 6.5 to 8.3 has been necessary. At higher pH values the effectiveness of chlorination decreases, *i.e.*, the rate of kill of microbes decreases.

6. Phosphate

In a natural, unpolluted water, phosphates are having little significance. However, due to the increased use of detergents and commercial fertilizers, phosphates are being discharged into lakes and streams in concentrations which greatly influence biological activities in these bodies of water. Hence they exert secondary effects on water supplies, which may necessitate the provision of additional treatment facilities. On the other hand, complex phosphates are

usually introduced into sources of supply for the prevention of corrosion and scaling in water distribution systems.

7. Radiological Limits

The exposure of humans to radiation has been considered as harmful. Exposure to ionizing radiation must be controlled and monitored. Concentrations exceeding the average values presented in Table 4.4 for a period of one year must constitute grounds for rejection. All samples for analysis from water supply systems must be composited over a three-month period and discharges receiving radioactive wastes have to be examined several times per year.

Table 4.4. Radiation Limits

Radionuclides	*Concentration, $\mu\mu Ci/litre$*
Radium-226 (^{226}Ra)	3
Strontium-90 (^{90}Sr)	10
Gross β-activity (^{90}Sr and α emitters absent)	1000

Where the total intake of ^{226}Ra and ^{90}Sr from all sources has been determined, the limits could be adjusted so that the total intake of ^{226}Ra and ^{90}Sr will not exceed 7.3 micro microcuries ($\mu\mu Ci$) per day and 73 $\mu\mu Ci$/day, respectively. When mixtures of ^{226}Ra and ^{90}Sr, and other radionuclides, are present, the above limiting values lust be modified to ensure that the combined intake has been notn mikely to result in radiation exposure in excess of the Radiatio Protection Guides. Radiation limits in certain mining operations, *e g.*, uranium, have been somewhat higher. The radioactivity limits for drinking water are : *acceptable*—1/3 of the International Commission in Radiological Protection (FCRP) of the maximum permissible concentration in water $(MPC)_w$ for a 168-hr week ; *maximum permissible limit*—the ICRP$(MPC)_w$ for 168-hr week ; *objective*—1/10 of the ICRP$(MPC)_w$ for 168 hr week.

The recommeded MPC in effect for some years has been 100 pCi/litre (picocuries or micromicrocuries/litre of air) of radon gas

in equilibrium with short-lived disintegration products ; the latter are RaA (polonium-218), RaB (lead-214), etc.

The lower MPC subsequently recommended by the ICRP has not received general acceptance.

8. Raw Water Quality

Raw water quality and standards depend upon the end use. The four main uses are municipal, industrial, agricultural, and recreational (fish and wildlife). Water controls the cost of many industrial products. A cheap supply is needed for support of all industry, and requirements for important industries are shown in Table 4.5.

Table 4.5. Typical industrial water requirements

Industrial uses	*Rates, gal*
Air conditioning	200-23,000/person/season
Brewing	300-1000 bbl beer
Coal washing	600-2400/ton coal
Coke	3600/ton coal
Sugar processing	20,000-25,000/ton sugar
Canning (corn, green beans, peas)	2500-3500/100 cases $\neq$2 cans
Meat (packing houses)	550-2000/animal
Poultry	2000/1000 lb live weight
Dairy	340/1000 lb milk and cream
Cheese	200/1000 lb milk and cream
Butter	250/100 lb butter
Vegetable dehydration	500-2000/100 lb
Oil field (secondary recovery)	42,000-504,000/1000 bbl crude
Oil refining	770,000/1000 bbl. crude
Pulp paper	120,000/ton paper
High-grade paper	250,000/ton paper
Textile (cotton)	10,000-40,000/1000 lb goods
Steel	20,000-35,000/ton
Electric power generation	80/kWh

QUALITY OF WATER FOR INDUSTRIAL USE

Absence of odours, slick and unslightly suspended or floating matter, D.O. *i.e.*, Dissolved oxygen (near saturation) mg/1 as daily average, always 1.0 mg/1, pH 5.0-9.0, temperature 21°C, dissolved solid 750 mg/1 as monthly average, always 1000 mg/1.

QUALITY OF WATER FOR RECREATIONAL BOATING

Absence of slick, odours, any visible floating and suspended solids, DO=5.0 mg/1 during at least 16 hr/day always 3.0 mg/1, CO_2 40 mg/1, preferable less than 20 mg/1, pH 5.0-9.0, daily average preferable 6.5.—8.5, temperature 20°C, toxic substance 0.1 median 48 hr—tolerance.

QUALITY OF WATER FOR BATHING

No visible sewage matter, DO near saturation ; bacterial standard coliform groups per 100 ml. A free chlorine residual of at least 0.4 ppm has to be maintained throughout the bathing pool.

5

Sampling Apparatus

INTRODUCTION

Fresh and marine water systems found out in situ (in place) or by collecting either the water or sediment and returning it to the laboratory for analysis. The type of information needed will generally determine whether the system has to be measured in situ or whether the material has to be removed from the system for laboratory analysis. For example, if information on water velocity and direction has been needed the water column could be measured in situ, whereas if various chemical parameters are to be determined, the water must generally be collected prior to analysis. In general, sampling and water measuring devices must be divided into five broad categories : *water samplers, bottom samplers, biological samplers, current-measuring devices, and turbidity-measuring devices.*

1. Water Samplers

In water sampling the problem of getting a water sample from a given depth and retrieving it without having the sample mix with water from other depths has been encountered. In addition, if the water temperature has to be measured, there must be a means to accomplish this without having the temperature of the sample change as it has been brought back to the ship. Specially designed *water*

bottles have been used to retrieve water from various depths. These bottles consist of open cylinders which attached to a weighted wire (*hydrowire*) and lowered to the desired depth. The bottles have been equipped with valves that get activated by a weight termed a *messinger*. The messinger has been attached to the wire and released. It travels down the wire and hits a trigger on the water bottle. This makes the valves to close, thereby collecting the water from that particular depth. After the messinger has tripped the valves (thereby collecting the water), the bottles get returned to the ship.

The most common water sampler in use has been the *Nansen bottle*. The Nansen bottle has been sent down to the required depth with the valves in the open position. At the desired depth a messinger would be sent down, which strikes the trigger on the Nansen bottle. The trigger releases the top portion of the bottle from the wire and makes the bottle to reverse (turn upside down). As the bottle turns over (it is, however, held to the wire by the bottom clamp), the valves close, getting the water sample.

The Nansen bottle has been made of metal lined with Teflon; it generally holds 1 litre of water. As the valves are metal, there has been the possibility that corrosive salts will adhere to them. Unfortunately, this provides a means of contaminating successive water samples. To get samples for chemical analysis, bottles constructed of an inert plastic with few if any metal parts have been preferred.

The water samples collected by these bottles can be used for various chemical and physical analysis. In addition, the particulate matter suspended in the sample could be removed by filtration and used in a variety of chemical, biological, or geological investigations. As the volume of the water sample has been accurately known, the concentrations of the various suspended and/or dissolved constituents comprising the sample could be accurately determined.

2. Temperature Measurements

Surface-water temperatures could be accurately measured by a simple thermometer. Measuring subsurface-water temperatures poses

a problem, however, in that the temperature cannot be found out after the water gets returned to the research vessel, because the temperature would change as the sample passes up through the various water levels, which can get expected to be at different water temperatures. Hence, subsurface-water temperatures could be generally measured either by reversing thermometers or with the bathythermograph.

3. Reversing Thermometers

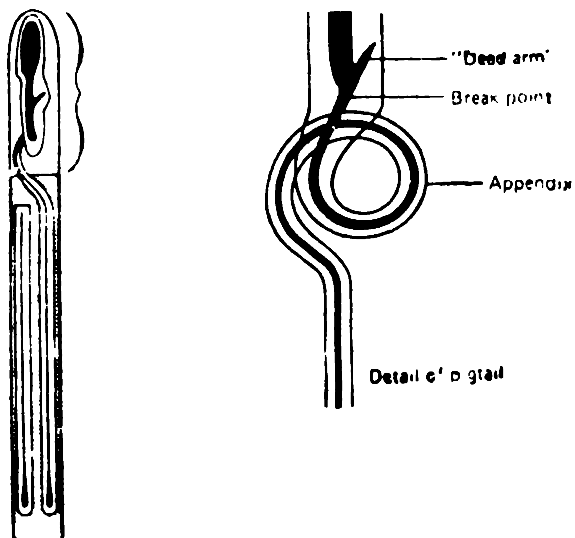
Reversing thermometers have been designed to get in situ subsurface-water temperatures. The thermometer (Fig. 5.1 A and B) consists of a capillary tube drawn out into a loop (pigtail) and a constriction (appendix) immediately above the mercury reservoir. The thermometer gets released in its upright position, and the mercury has been able to pass freely from the reservoir into the capillary tube in response to the surrounding temperature. If the thermometer reverses, the mercury column separates from the reservoir and gets trapped in this position to give the temperature of the water at the instant of reversal.

The Nansen bottle has been designed to hold reversing thermometers on their outer wall, and water temperature could be taken in situ at the same time that the actual water sample has been obtained. Hence the temperature has been taken by the thermometers at the same instant that the water sample has been taken in the Nansen bottle. Generally, both a shielded and an unshielded thermometer get attached to the outer wall of the Nansen bottle and have been sent to the desired depth. These thermometers have been identical except that the shielded thermometer has heen completely enclosed in a protective glass case, has been not affected by pressure changes, and responds only to the temperature of the water at the depth to which it is sent. The unshielded thermometer has been open at the bottom, permitting the surrounding water to enter the case and thus exert pressure on the thermometer. The pressure exerted on the unshielded thermometer has been, obviously, a function of the depth to which it has been sent. As the Nansen bottle having the thermo-

meters reaches the desired depth, the thermometers are allowed to equilibriate prior to getting the water-sample and temperature information. In the shielded thermometer the mercury responds only to the temperature of the surrounding water, while in the un-shielded thermometer the mercury would respond to both the wa'er temperature and the hydrostatic pressure.

Whe the messinger trips the Nansen bottle it reverses, collecting the water sample. As noted above, when the thermometers reverse, the mercury column get separated from the mercury contained in the reservoir and falls to the opposite end of the thermometer. As it has been detached from the reservoir at this stage, it no longer has been able to respond to temperature changes. The shielded thermometer provides the actual in situ temperature, whereas the unshielded thermometer provides a temperature reading as affected by the pressure.

The pressure exerted by subsurface water has been a function of depth and will make the unshielded thermometer to give a false



(*a*) (*b*)

Fig. 5 1. *Shielded thermometer with detail of pigtail.*

(high) temperature reading. Hence, a comparison of the actual temperature (from the shielded thermometer) with the false temperature combined with the density of the surrounding water (obtained from the collected water sample) makes the depth at which the water sample is collected to be calculated. It is a definite advantage, for, although the depth could be calculated by measuring the amount of wire (attached to the Nansen bottles) that has been played out, this gives only an estimate of the actual depth. It has been due to the fact that currents, vessel drift, and wind will make the wire to descend on an angle, thereby giving a false measurement of the actual depth at which the sample was taken.

4. Bathythermographs

Although the *bathythermograph* is not as accurate as the reversing thermometer, it permits continuous measurement of temperature versus depth and permits these data to be collected more rapidly.

The bathythermograph has been consisting of a temperature-sensitive element that scribes a tracing on a coated-glass slide in response to changing temperatures. The slide itself has been mounted on a pressure-sensitive spring-loaded bellows that contracts in response to changing temperatures over a slide that moves in response to changing pressures (due to and correlated with water depths). These two motions make the stylus to trace a temperature-depth curve on the slide as the bathythermograph gets lowered into the water column. Upon retrieval of the instrument, the slide could be removed, kept against a calibrated grid, and "read". The slide may be retained and therefore provide a permanent record of temperature versus depth at a given station.

BOTTOM-SAMPLING DEVICES

The three basic devices which are utilized to obtain bottom samples have been dredges, grabs, and coring devices. Both dredges and grabs have been able to take samples for both geological and biological analysis but have been incapable of getting undisturbed samples. Coring devices, on the other hand, have been able to get

undisturbed bottom samples that permit the investigator to study sediments in the order in which they were initially deposited. Corers do not, however, get samples of sufficient quantity to allow biological analysis of organisms other than the microfauna (*Foraminifera*).

1. Dredges Samplers

A *dredge* has been a boxlike apparatus that could be lowered onto the bottom and dragged behind a ship. When it moves over the bottom, the dredge scrapes biological samples from the surface and digs into the softer sediments, getting, by this means, a sample of bottom organisms, small rock, sand, and mud. A wire or cloth mesh liner is kept inside the dredge to allow the free flow of water but to retain the sediment and biological materials that enter. The mesh size determines the size of the material that is collected. As a dredge tends to skip and bounce over the sediment as it gets towed, It does not obtain a quantitative sample, and, as noted above, the sample tends to become well mixed in the process.

2. Grab Samplers

Grab samplers have been available in several forms. The basic design, however, consists of a pair of jaws and an upper reservoir to hold the sample. Grabs have been generally released from the ship with the jaws open ; as the sampler strikes the bottom, the jaws get "tripped" and snap shut, getting the sample. Water that washes through the reservoir as the grab gets returned to the surface tends to stir and disturb the collected sediment. In addition, pebbles or shells often tend to keep the jaws partially open so that the sample has been washed out and lost during retrieval

3. Coring Devices

Coring devices, like grab samples, have been available in several different designs and modifications. In its simplest form (Fig. 5.2), a coring device is having a hollow metal tube with a weighted upper end. The tube has been designed to separate toward the middle to allow the insertion of a plastic core-tube liner into its lower section. Attached to the bottom of the metal tube has been a sharp cutter

head, which facilitates the passage of the tube into the sediment. Attached to the upper end of the metal tube has been a flap that serves to create suction on the system after the sample has been obtained. The entire apparatus has been attached to a line or cable aboard a ship, and the flap has been kept in the open position. The coring device has been then released and allowed to freefall through the water column.

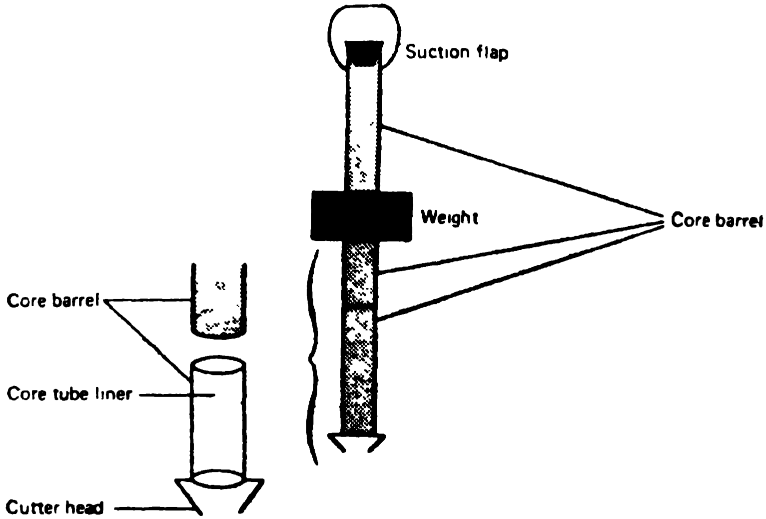


Fig. 5.2. Coring device.

When it strikes the sediment, the weight drives the core barrel into the substrate, and the sediment enters the core-tube liner. Simultaneously, the flap snaps shut and produces suction on the system. The suction permits the sediment to be held firmly in the core-tube liner. The apparatus is then returned to the ship and the liner holding the sediment has been removed from the barrel and saved for analysis.

BIOLOGICAL SAMPLERS

Bottom organisms have been generally obtained by dredging and grab sampling. Organisms that inhabit the water column (plankton, fish, etc.) have been generally collected in nets of various meshes. The mesh size, obviously, decides the size of the organism collected. Some nets have been designed to be sent down to a given

depth in the closed position. At the required depth a messinger has been sent down to open the net, which then collects the desired sample. After the sample has been collected, the net may be reclosed and brought back to the ship in this position. In this manner only organisms that inhabit a given depth are collected. Many nets (especially plankton nets) are having a propeller-device meter which is attached to the front of the net. The water passing into the net turns the propeller on the meter and provides an accurate measure of the water passing through the net. In this way the number of organisms per unit volume of water can be found out.

A net termed a *bottom trawl* has been often used in lieu of dredges and grabs to get large bottom-dwelling organisms. The bottom trawl has been consisting of large mesh nets that drag along the bottom and collect whatever is in their path.

CURRENT MEASUREMENTS

Several means have been available to measure water movement. In marine systems and large lakes, current meters, fluorescing dyes, and float bottles are generally used. In groundwater systems the movement of fluorescing dyes or chloride ions has been generally traced.

1. Current Meters

Two basic types of current meters have been presently in use : the *mechanical current meter* and the more modern *electronic meters.* The *mechanical current meter* is having a current rotor and a system of dials. The rotor is made to spin in response to the current and releases a bronze pellet after completing every 30 revolutions. The pellets fall into compartmentalized slots which correspond to compass points and have been used to indicate direction. Hence the number of pellets released reveals the total number of revolutions completed by the propeller (water speed), and the distribution of the has been used to indicate water direction.

Each series of measurements employing a mechanical meter of this type entails removing the meter from the water, recording the

data (the number of pellets released and the distribution in directional compartments), resetting the meter, and keeping it at the desired depth for the next series of measurements. In addition, no information on the variability of speed can be found out.

Electronic current meters are having a rotorlike device that could be turned by the passing water. When the rotor turns, it generates an electric current which gets transmitted to the ship and has been used to drive a meter or chart recorder pen. A magnetic or gyroscopic compass is also attached to either the current-meter body or to the directional vane. The orientation of the compass has been electrically sensed and has been also transmitted to the ship, where it has been presented as a meter reading or as a strip-chart recording. Electronic current meters provide a continuous measurement of current velocity and direction.

2. Drift Bottles

Drift bottles provide the aveiage direction and speed of the currents in which they have been kept. A drift bottle has been a sealed container that is weighted to be of the same density as the water mass to be traced. The weighted drift bottle is kept in the appropriate water mass and released. Inside each drift bottle has been a card that requests the finder to fill in the date and place of recovery and return the card to the institution performing the study. When the card gets returned, the average speed and direction taken by the bottle can be found out. Plastic cards, serving the same purpose, have been generally used instead of drift bottles at present.

3. Dye Studies

Fluorescing dyes have been often released into water masses and employed to trace the path of these waters. These dyes have been readily visible in high concentrations and are easily detected by using a fluorometer in trace amounts (ppm and ppb). Generally, the dye has been mixed with water and prepared to be of the same density as the water mass in which it has to be released. After the dye gets released, a ship will set up a series of stations from the point of dye input, and water samples would be obtained and analyzed fluorometrically.

4. Use of Chloride Ions

In many groundwater systems it has been observed that dissolved ions, like iron, fluoresce over a very wide range and interfere with the detection of the fluorescent dye customarily used. In these cases sodium chloride has been employed in place of the dye. The sodium chloride, when dissolved in water, dissociates into its component ions (Na^+ and Cl^-), and these ions will tend to travel as a part of the water mass in which they get dissolved. As normal groundwater contains no chloride ions, any chloride detected in test wells downgradient of the point of input can be regarded to have been placed there as a part of the study. The presence of chloride ions could be easily determined by silver nitrate titration.

TURBIDITY-MEASURING DEVICES

The degree of water transparency (*turbidity*) has been of importance because it indicates the amount of suspended solids in the water column and reveals the extent of the euphotic zone. The turbidity of water is or electronically by a hydrophotometer.

The Secchi disk has been a white, or black-and-white, disk that has been lowered into the water column on a line marked off in meters. The disk has been lowered until it disappears from view and has been then returned to the ship. As it has been returned, the number of meters of line that had initially been played out has been determined and noted. This gives the transparency of the water column.

Transparency could also be determined by using a hydrophotometer. This device is having a light source and a photo cell. It is similar, although simpler, than a spectrophotometer. Light passes through the water sample and strikes the phototube. The phototube is able to convert the light energy to electrical energy, which is then used to drive a meter calibrated in percent light transmission. As the amount of dissolved material increases, less light would strike the phototube and the light transmission of the sample gets decreased.

6

Water Analysis Methods

INTRODUCTION

This chapter discusses the more common analytical methods which are used in water analysis. After the samples have been collected, they must be preserved if the analysis is to be delayed. The guidelines for the preservation of samples, as well as the recommended holding times, are given in Table 6.1.

Table 6.1. Methods of Sample Preservation

Analysis	*Preservative*	*Holding Time*
pH	Determine on site, or hold at 4°C	6 hours
Heavy metals	Adjust to pH 2 with HNO_3	6 months
BOD	Hold at 4°C	6 hours
COD	Adjust to pH 2 with H_2SO_4	7 days
Chloride	Filter on site ; hold at 4°C	7 days
Dissolved oxygen	Determine on site, or see p. 221	
Nitrate; nitrite	Filter on site; adjust to pH 2 with H_2SO_4; hold at 4°C	24 hours
Phosphate	Filter on site; hold at 4°C	24 hours
Turbidity	Hold at 4°C	7 days

SALINITY ANALYSIS

Salinity could be measured by analyzing a given water sample for the chloride concentration by titration with silver nitrate; from these data, the salinity could be calculated. Because of the constancy of composition of seawater it has been possible to calculate salinity from chlorinity.

It becomes necessary to standardize the silver nitrate because all laboratories that perform salinity determinations similarly standardize their $AgNO_3$. This permits the laboratories to carry out the analysis with a standard concentration of $AgNO_3$, thus getting uniform results among all laboratories.

It is known that the silver nitrate reacts stoichiometrically in an exact 1 : 1 ratio with chloride ions. Therefore, ideally if the silver nitrate solution has been prepared properly, exactly 1 ml of $AgNO_3$ must react completely with 1 ml of standard, 10 ml of $AgNO_3$ must react completely with exactly 10 ml of the standard, and so on. If, however, the $AgNO_3$ has been too dilute, more than 10 ml of $AgNO_3$ will be needed to react completely with exactly 10 ml of the standard. Conversely, if the $AgNO_3$ has been too concentrated, the opposite will take place.

After the $AgNO_3$ has been standardized, the samples could be analyzed and the chlorinity determined. The salinity may then be found out by use of conversion tables or by using the formula $S‰_0 = 1.805\ (Cl‰_0 = a) + 0.03$, in which $Cl‰_0$ could be obtained directly from the buret reading.

Reagents

(*i*) Standard seawater.

(*ii*) Silver nitrate solution (0.28 N).

(*iii*) Chromate indicator.

Silver Nitrate Standardization

(*i*) As each lot of sea water varies slightly in its stated chlorinity (the chlorinity is precisely known and stated, but it varies with each lot), it becomes necessary to calculate the number of milli-

litres of $AgNO_3$ to reach an end point with that particular lot of sea water. This is done by considering that the $AgNO_3$ has been prepared exactly and then carrying out the calculation ; for example, if the stated Cl‰ of the standard seawater has been 19‰ and the $AgNO_3$ has been prepared to be 19‰, the required number of millilitres of $AgNO_3$ required to reach the end point is calculated by the formula $ml \times Cl‰$ (of standard)$=ml \times Ag‰$ (of silver nitrate). This calculation will give the number of millilitres of $AgNO_3$ needed to reach an end point, assuming that the $AgNO_3$ was prepared precisely. The deviation from this number will give the α factor.

(*ii*) Keep exactly 10.00 ml of the Copenhagen water in a 250-ml beaker, and add 15 ml of the potassium chromate indicator.

(*iii*) Keep the $AgNO_3$ in the buret and carry out the titration. The end point is marked by the formation of a persistent faint brownish-red color.

(*iv*) The titration must be repeated five times, the results averaged, and the α determined.

(*v*) The α must be noted and kept on the stock $AgNO_3$ storage bottle.

Analytical Procedure

(*i*) Transfer 10.0 ml of sample to the beaker, add 15 ml of the indicator, and titrate with the standardized $AgNO_3$ to the proper end point.

(*ii*) Note volume of the $AgNO_3$ added (it is approximately equal to the Cl‰).

Calculations

(*i*) The S‰ could be calculated from the Cl‰ by use of conversion tables, or

(*ii*) By means of the formula $S‰=1.805\ (Cl‰ \pm \alpha)+0.03$.

Note. *This method can also be used for tracing the movement of groundwater.*

OXYGEN ANALYSIS

Three analytical methods may be used in the determination of oxygen levels : ***dissolved oxygen analysis*** ***(DO)***, ***biological oxygen demand*** ***(BOD)***, and ***chemical oxygen demand*** ***(COD)***. The choice of analysis has been dependent upon the data needed and the origin of the water sample under analysis. For example, DO is commonly carried out on samples taken from natural systems. The BOD has been a measure of the oxygen removed from systems over a given period of time by biological activity in the course of the decomposition of organic material. BODs are commonly undertaken in areas where there is a known or suspected input of organic material. The COD has been a measure of the oxygen demand placed on a given system by chemical input (chemical oxidants). This method would be carried out on waters receiving, or suspected of receiving, this type of input. The methods for DO, BOD, and COD analysis follow.

DISSOLVED OXYGEN

(Standard Methods) : Method I

In the determination of dissolved oxygen, various ions and compounds have been found to interfere with the analysis. Consequently, there have been several methods which are devised to correct for these interferences. The method given below, termed the *azide modification*, most effectively removes the interference due to nitrite. This is a titrametric method in which the sample, following various preparatory steps, has been titrated with a standard solution of sodium thiosulfate to a pale-straw-colored end point.

Reagents

(*i*) *Manganese sulfate solution.* Weigh and dissolve 480 g of $MnSO_4 \cdot 4H_2O$ in distilled water, filter, transfer to a 1-litre volumetric flask, and dilute to the mark.

(*ii*) *Alkali iodide-azide reagent.* Weigh and dissolve 500 g of NaOH and 135 g of NaI in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark.

(*iii*) Dissolve 10 g of NaN_3 in 40 ml of distilled water and add to the NaOH-NaI solution. When this solution is added to the starch solution, diluted, and acidified, it should not give a color.

(*iv*) Concentrated H_2SO_4.

(*v*) *Starch solution*.

(*vi*) *Sodium thiosulfate stock solution* (0.10 N).

(*vii*) *Standard thiosulfate titrant* (0.025 N).

(*viii*) *Standard potassium dichromate solution* (0.025 N).

Standardization of the thiosulfate. Dissolve 2 g of KI in 150 ml of distilled water. To this add 10 ml of H_2SO_4, followed by exactly 20.00 ml of the $K_2Cr_2O_7$ standard. Dilute to 200 ml and titrate with the thiosulfate standard. If a pale straw color is achieved (toward the end of the titration), add 2 ml of the starch solution. The addition of the starch will be marked by the formation of a blue color (the iodine-starch reaction). Continue the addition of thiosulfate to the first disappearance of the blue color. Considering that the thiosulfate is exactly 0.025 N, precisely 20.00 ml of thiosulfate should be needed to reach the end point. If necessary, it becomes convenient to adjust the concentration of the thiosulfate (on the basis of the standardization) to 0.025 N to avoid additional calculations.

Sampling and analytical procedure. All water samples must be collected in BOD bottles. These bottles are having a capacity of either 250 or 300 ml and are sealed with a ground-glass stopper that prevents the addition of atmospheric air. If the sample is collected, the bottle must be "overfilled" with the sample and the stopper promply inserted. At this time some of the sample will overflow from the bottle. If this method is followed, no air will get trapped inside the bottle. It becomes necessary to eliminate air from the BOD bottle in this manner, since trapped air will tend to diffuse into the sample, yielding erroneous results. If reagents are added to the sample (in the BOD bottle), the pipet is kept in the bottom of the bottle and the reagent added. By this manner of addition, mechanical stirring at the sample surface could be minimized. After

the addition of reagents, the bottle has been tightly stoppered and stored for analysis.

(*a*) To the samples collected in the BOD bottles, add 2 ml of the manganese sulfate solution, followed by 2 ml of the alkali iodide-azide reagent by the method described above. Stopper the BOD bottle and mix by inverting the bottle several times. A manganese hydroxide precipitate will form. Remix and allow to settle.

(*b*) When settling has produced 100 ml of clear supernate, add 2.0 ml of concentrated H_2SO_4 by the method given above. Restopper immediately and mix by inversion.

(*c*) The sample could now be removed from the BOD bottle for analysis. In calculating the volume of sample to be titrated, it becomes necessary to compensate for the loss of the original sample by addition of the reagents.

(*d*) Titrate 200 ml of sample (after correcting for addition of reagents) with 0.025 N thiosulfate solution to a pale straw color.

(*e*) After the straw color has been obtained, add 2 ml of starch solution and continue the addition of thiosulfate until the first disappearance of the blue color. Note the volume of thiosulfate used.

Calculations. Since exactly 1 ml of 0.025 N thiosulfate is equivalent to 0.2 mg of DO, each millilitre of thiosulfate used in the titration is equivalent to 1 mg/litre of DO, assuming that a volume equivalent to 200 ml of original sample is titrated. Thus a direct reading of the buret will give mg/litre DO.

DISSOTVED OXYGEN
(ALTERNATIVE METHOD FOR MARINE WATERS)
METHOD II

The following method has been commonly used in the analysis of sea-water samples. It is a modification of the previous method and also is based upon the titration of the sample with a sodium thiosulfate solution.

Reagents

(*a*) *Man,anous sulfate reagent.* Weigh and dissolve 480 g of $MnSO_4.4H_2O$ in distilled water and dilute to the mark in a 1-litre volumetric flask.

(*b*) *Alkaline iodide solution.* Weigh and dissolve 500 g of NaOH in 500 ml of distilled water. Dissolve 300 g of potassium iodide in 450 ml of distilled water. Mix the two solutions.

(*c*) *Starch-indicator solution.*

(*d*) *Standard thiosulfate solution (0.01 N).*

(*e*) *Iodate solution (0.0100 N).* Dissolve with gentle warming exactly 0.3567 g KIO_3 in distilled water, cool, transfer to a 1-litre volumetric flask, and dilute to the mark. In this method, the standard sodium thiosulfate solution could be "corrected" by titration against the iodate solution. The correction has been in the form of a numerical *f* factor which must be used in all oxygen calculations.

(*f*) *Factor determination*

(*a*) Fill a 300-ml BOD bottle (see Appendix III, Part B, Method A) with distilled water. To this 1.0 ml of concentrated H_2SO_4 and 1.0 ml of alkaline iodide solution ; restopper and mix.

(*b*) Add 1.0 ml of manganous sulfate solution ; restopper and mix.

(*c*) Transfer 50-ml aliquots (portions) and keep in the titration flask.

(*d*) Add 5.00 ml of 0.0100 N iodate standard. Allow to stand 3 minutes.

(*e*) Titrate this solution with the 0.01 N thiosulfate solution.

(*f*) The *f* factor could be calculated from the following equation in which *v* equals the volume of standard thiosulfate used to reach the end point :

$$f = \frac{5.00}{v}$$

Sampling and analytical procedure. It becomes necessary to use 300-ml BOD bottles in this method. These bottles must be

rinsed twice with portions of the sample being collected to prevent contamination. If the sample is obtained by use of a Nansen bottle, a length of rubber tubing has to be run from the top to the bottom of the BOD bottle. This will disallow mechanical stirring at the sample surface. Water is allowed to overflow from the top of the BOD bottle, which is then tightly stoppered. The water to be used for oxygen analysis should be the first samples drawn from the sample bottles.

Procedure

(*a*) Remove the stopper from the BOD bottle and add 1.0 ml of manganous sulphate and 1.0 ml of alkaline iodide solution to the bottom of the sample. Restopper and mix until the precipitate has been uniformitly dispersed.

(*b*) The precipitate should settle in 2 to 3 minutes ; at that time mix again. Keep the samples to stand until the precipitate has settled at least one third of the way down the bottle and the supernatent is clear.

(*c*) Add 1.0 ml of concentrated H_2SO_4, restopper, and mix until the precipitate is dissolved.

(*d*) Keep 50.0 ml of the sample in the painted Erlenmeyer flasks. Titrate with the standard thiosulfate solution. Thiosulfate is added until a pale-straw-colored solution is obtained. To this add 5 ml of the soluble starch solution. The solution will turn blue with this addition. Continue the titration nntil the blue disappears. Record the volume of thiosulfate used. The oxygen could be calculated from the following formula, in which v equals the volume of thiosulfate added to reach the end point, and f is the correction factor obtained in the standardization of the thiosulfate :

$$\text{mg—at } O_2/\text{litre} = 0.1006 \times f \times v$$

(*a*) A BOD bottle is filled with distilled water and 1.0 ml of concentrated H_2SO_4 and 1.0 ml of alkaline iodide is added. The solution is then mixed

(*b*) 1 ml of manganous sulfate is added and the solution remixed.

(*c*) 50.0 ml of this solution is placed in the Erlenmeyer flask.

(*d*) This solution has been titrated with thiosulfate until colorless. The volume is noted. This volume serves as the blank and, if necessary, has been subtracted from the final volume of the thiosulfate in both the sample titration and the standardization of the thiosulfate, prior to performing any further calculations (*f* factor and/or O_2 concentrations). If the blank exceeds 0.1 ml, the reagents should be neglected and new ones prepared.

BIOLOGICAL OXYGEN DEMAND

The decomposition of sewage, sewage-plant effluents, and agricultural and industrial wastes would be able to deplete the oxygen (increase the oxygen demand) in waters receiving these materials. The oxygen demand in any system could be increased by the input of three broad classes of materials : (1) carbonaceous organic material, which is used as an energy source by aerobic organisms ; (2) oxidizable nitrogen derived from nitrite, ammonia, and organic nitrogenous compounds, which sesve as an energy source for specific microorganisms such as *Nitrosomonas* and *Nitrobacter* and (3) chemical-reducing compounds such as Fe (III), sulfite, and sulfide, which react with and consume dissolved oxygen.

In raw and settled domestic sewage, the ovygen demand could be brought about by the first class of materials, and the oxygen demand has been biological in nature (BOD). In biologically, treated effluents the oxygen demand has been also biological in nature and has been brought about by the second classs of materials.

As most wastes are complex and have a variety of organic compounds not readily decomposed by biological activity, the oxygen demand placed on a system to accomplish the complete decomposition of this material has been not measured. Rather, a 5-day BOD analysis could be done and this 5-day BOD has been a generally accepted standard test. In many cases it is necessary to

add microorganisms to the sample under investigation in order to obtain a valid BOD. This is termed *seeding.*

If seeding is necessary, the seed found to be satisfactory for the particular water under study is added to the dilution water (see 1 under Procedure).

Apparatus

(*a*) *300-ml BOD bottles.*

(*b*) *Incubator (either air or water).* The incubator must be thermostatically controlled at 20°C$\pm$1°C.

Reagents

(*a*) *Phosphate buffer solution.* Weigh and dissolved 8.5 g of KH_2PO_4, 21.75 g of K_2HPO_4, 33.4 g of $Na_2HPO_4.7H_2O$, and 1.7 g NH_4Cl in approximately 500 ml of distilled water, transfer to a 1-litre volumeteric flask and dilute to the mark. The pH of this solution should be 7.2 without further adjustment.

(*b*) *Magnesium sulfate solution.* Weigh and dissolve 22.5 g of $MgSO_4.7H_2O$ in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark.

(*c*) *Calcim chloride solution.* Weigh and dissolve 27.5 g of anhydrous $CaCl_2$ in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark.

(*d*) *Ferric chloride solution.* Weigh and dissolve 0.25 g of $FeCl_3.6H_2O$ in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark.

(*e*) 1 litre of 1 N H_2SO_4.

(*f*) 1 litre of 1 N NaOH.

(*g*) *Sodium sulfite solution (0.025 N).* Weigh and dissolve 1.575 g of anhydrous Na_2SO_3 in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark. This solution is unstable and should be prepared daily.

Procedure

Adjust the pH of the samples to 7 with 1 N H_2SO_4 or 1 N NaOH prior to beginning the analysis.

(*a*) *Dilution water.* The distilled water used as dilution water must be stored in cotton-plugged bottles for a sufficient length of time to have become saturated with dissolved oxygen. If necessary, the water may be aerated by bubbling air into the water.

(*b*) If necessary, the dilution water must be seeded at this point.

(*c*) *Dilution of samples* : It becomes necessary to make several dilutions of the sample to get the required oxygen depletions. The following dilutions have been recommended : 0.1 to 1.0% for strong trade wastes, 1 to 5% for raw and settled sewage, 5 to 25% for oxidized effluents, 25 to 100% for polluted river waters.

(*i*) Carefully siphon the required volume of dilution water (seeded if necessary) into a 1- or 2-litre graduated cylinder, avoiding the aeration of the water.

(*ii*) Add a sufficient quantity of sample to prepare the proper dilution (see 3 above). Mix well with a plunger-type mixing rod to avoid the addition of air.

(*iii*) Siphon the diluted sample into two BOD bottles.

(*iv*) One bottle is incubated at 20°C for 5 days.

(*v*) The dissolved oxygen in the second bottle is determined immediately by the method given in Appendix III, Part B, or by the use of an oxygen meter. This will give the initial dissolved oxygen concentration of the sample.

(*vi*) Prepare succeeding dilutions of lower concentrations in the same manner. Using a raw sewage sample as an example : the initial dilution must prepare a 5% solution of raw sewage, while the succeeding dilutions would be performed to prepare 4, 3, 2, and 1% solutions.

(*d*) All samples and blank dilution water samples (dilution water with no sample added) must be incubated for 5 days at 20°C.

(*e*) After incubation the oxygen levels of all samples and the blank dilution water could be determined by the method given in Appendix III, Part B, or by use of an oxygen meter.

(*f*) Those dilutions showing a residual DO of at least 1 mg/litre and a depletion of at least 2 mg/litre have been regarded to be the most reliable.

Seed correction. If it becomes necessary to seed the sample to obtain a suitable oxygen reduction, the oxygen depletion of the seed may be determined as follows. A separate series of seed dilutions have been set up and incubated. The samples resulting in a 40 to 70% reduction in oxygen are selected, and one of these samples has been used to calculate the seed correction. The correction is calculated by the formula

$$\text{seed correction} = (B_1 - B_2) = f$$

The f factor could be determined by the formula

$$f = \frac{\%\ \text{seed in } D_1}{\%\ \text{seed in } B_2}$$

in which D_1=dissolved oxygen 15 minutes after preparation
B_1=dissolved oxygen of seed before incubation
B_2=dissolved oxygen of seed after incubation
f=ratio of seed in sample to seed in control

If applicable, the seed correction is then used in the final oxygen calculation.

CHEMICAL OXYGEN METHOD

The determination of the chemical oxygen demand of a system depends upon the determination of those compounds that have been capable of undergoing chemical oxidation. The decomposition of these materials has been chemical in nature and serves to reduce the available oxygen within a system. The COD of a system has been found to vary with the water composition, temperature, and contact time. In some cases there is a degree of correlation between BOD and COD. Generally, however, chemical decomposition and biological decomposition have been separate and distinct processes, and the results could vary.

Most types of organic matter could be destroyed by boiling in a mixture of chromic acid and sulfuric acid. The amount of organic

matter liberated is then found out by titration with ferrous ammonium sulfate and the COD calculated. The procedure follows :

Apparatus

(*a*) Reflux condensers.
(*b*) 500-ml round-bottomed flasks with ground-glass necks.
(*c*) Heating mantles.

Reagents

(*a*) *Standard potassium dichromate solution (0.250 N).* Weigh and dissolve 12.259 g of $K_2Cr_2O_7$ (primary standard grade) in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark. Add 0.12 g of sulfamic acid to the standard so as to eliminate nitrate interference.

(*b*) *Sulfuric acid reagent.* Weigh and dissolve 22 g of silver sulfate per 9-lb bottle H_2SO_4. It will take 1 to 2 days for the silver sulfate to dissolve. If this quantity of reagent has been not required the concentrations be varied accordingly.

(*c*) *Standard ferrous ammonium sulfate reagent (00.1 N).* Weigh and dissolve 39 g of analytical-grade Fe $(NH_4)_2.(SO_4)_2.6H_2O$ in distilled water, add 20 ml of concentrated H_2SO_4, cool, transfer to a 1-litre volumetric flask, and dilute to the mark.

(*d*) *Ferroin indicator solution.* Weigh and dissolve 1.485 g of 1, 10-phenanthroline monohydrate and 0.695 g of $FeSO_4.7H_2O$ in distilled water and dilute to 100 ml.

(*e*) *Mercuric sulfate crystals.*

Standardization

(*a*) Dilute 10.0 ml of the standard potassium dichromate to 100 ml. To this add 30 ml of concentrated H_2SO_4. Allow to cool.

(*b*) Titrate this solution with the ferrous ammonium sulfate titrant using 2 drops of ferrion as the indicator. The normality of the ferrous ammonium sulfate may be found out by the formula

$$N = \frac{\text{ml of } K_2Cr_2O_7 \times 0.25\ N}{\text{ml of Fe } (NH_4)_2\ (SO_4)_2} \text{ (used to reach the end point)}$$

Procedure

(*a*) Keep 0.4 g of $HgSO_4$ in the reflux flask (500-ml round-bottomed flask) and add 20.0 ml of the water sample. Swirl to mix.

(*b*) Add 10.0 ml of the standard potassium dichromate solution.

(*c*) Add 30 ml of sulfuric acid reagent.

(*d*) Add 5 to 6 boiling chips to prevent "bumping" during the refluxing.

(*e*) Attach the flask to the reflux condenser and reflux for 2 hours.

(*f*) After refluxing, the solution is cooled and the reflux condenser is washed down with a minimum of distilled water.

(*g*) Detach the flask from the condenser and measure the volume of the solution. Bring up to a volume of 140 ml with distilled water if necessary.

(*h*) To this add 3 drops of the ferrion indicator and titrate to a reddish-brown end point with the standardized ferrous ammonium sulfate titrant.

(*i*) A blank having 20 ml of distilled water in place of the sample could be treated, refluxed, and titrated in the same manner.

Calculations. The COD is calculated from the equation

$$\text{mg/litre of COD} = \frac{(a-b)\ c \times 8000}{\text{ml of sample}}$$

in which a=ml of $Fe(NH_4)_2\ (SO_4)_2$ used for blank

b=ml of $Fe(NH_4)_2\ (SO_4)_2$ used for sample

c=ml of $Fe(NH_4)_2\ (SO_4)_2$ (determined in standardization with $K_2Cr_2O_7$)

SPECTROPHOTOMETRIC METHODS OF ANALYSIS

Many spectrophotometric methods have been available for the analysis of water and wastewater samples. The majority used either the visible spectrophotometer (generally the Spectronic 20) or, the

atomic-absorption spectrophotometer. In some cases, however, particularly when analyzing oceanic samples of low concentration, a spectrophotometer, having a 100-mm light path may be needed. The methods described here have been for the commonly measured parameters of orthophosphate, nitrite, nitrate, detergents, and a brief section is included on metal analysis.

NITRATE NITRITE

In this method the nitrate must be converted to nitrite before analysis. This conversion is done by passing the water sample through a column which is packed with granulated copper-cadmium. This process is able to convert the NO_3 to NO_2, which is then made to react with a chromogenic reagent and analyzed spectrophotometrically.

This method may be used to determine only the nitrite concentration (by analyzing the sample directly without passing it through the Cu-Cd column) or to determine both nitrate and nitrite. This is carried out by analyzing a portion (A) of the sample directly as discussed above to determine the NO_2 concentration. The remainder of the sample (B) is then allowed to pass through the column, the NO_3 is converted to NO_2 ; the sample is analyzed and the NO_2 concentration in sample A is subtracted from the NO_2 concentration in sample B (NO_2 plus converted NO_3). This will yield the NO_3 concentration (NO_3 converted to NO_2 in the column). This method is used for the analysis of drinking water, groundwater, surface fresh water, marine waters, and domestic and industrial wastewater.

It is to be noted that the method described here determines both nitrate and nitrite. If only nitrate analysis is to be done a separate determination must be done for nitrite and the appropriate corrections made. The nitrite may be determined without passing the sample through the column (see Analysis of Samples, below).

The apparatus needed for this analysis has been a spectrophotometer for use at a monochrometer setting of 540 nm with a light path of 1 cm or longer and the Cd-Cu column. The column

could be constructed of a 22-cm-long glass tube with a 3.5-mm inside diameter. The copperized cadmium is added to the column in sufficient quantity so that it fills at least 18.5 cm of its length. The reservoir (to contain the water and reagents) has been attached to the upper portion and may be constructed of a 100-ml plastic sample bottle by merely cutting off the bottom portion. A section of Tygon tubing with a pinch or screw clamp may serve a convenient stopcock on the opposite end.

Preparation of copperized cadmium (column packing)

1. *Granulated cadmium.* 40-60 mesh

2. *Copper-cadmium.* The granulated Cd is cleaned with 6 N HCl and copperized with a 2% by weight solution of $CuSO_4$ in the following manner :

(*i*) Wash the Cd with 6 N HCl. Then rinse it with distilled water.

(*ii*) Swirl 25-g portions of Cd in 100-ml portions of 2% $CuSO_4$ until the initial blue color fades. Decant and repeat with fresh $CuSO_4$.

(*iii*) Wash the Cu-Cd with distilled water (at least 10 washings are required) so as to remove all the precipitated copper.

Column preparation

(*a*) Insert a glass-wool plug into the bottom of the column and fill with distilled water. To this add sufficient Cu-Cd to produce a column 18.5 cm in length.

(*b*) Pass 200 ml of *dilute* ammonium chloride—EDTA solution.

(*i*) It is possible to prepare stock solution by dissolving 13 g of ammonium chloride and 1.7 g of disodium ethylene diaminetetraacetatic acid in 900 ml of distilled water. Adjust pH to 8.5 with concentrated ammonium hydroxide, transfer to a 1-litre volumetric flask, and dilute to the mark.

(*ii*) It is possible to prepare the dilute solution by diluting 300 ml of the stock solution to 500 ml with distilled water in a volumetric flask.

(*c*) After passing the dilute solution of ammonium chloride-EDTA through the column, the column could be activated by passing 100 ml of a solution composed of 25 ml of a 1.0 mg/litre NO_3-N standard mixed with 75 ml of the *stock* ammonium chloride—EDTA solution through the column at a flow rate of 7 to 10 ml/minute. After it is accomplished, the column has to be activated.

Reagents. The following reagents are necessary for the analysis :

(*a*) *Color reagent.* Weigh and dissolve 10 g of sulfanilimide and 1 g of *N* (1-naphthyl)-ethylenediamine dihydrochloride in a prepared solution of 100 ml of concentrated phosphoric acid in 500 ml of distilled water and dilute to 1 litre with distilled water.

(*b*) *Zinc sulfate solution* : weigh and dissolve 100 g of $ZnSO_4 \cdot 7H_2O$ in distilled water, transfer to 1-litre volumetric flask, and dilute to the mark.

(*c*) *6* N NaOH.

(*d*) Concentrated ammonium hydroxide.

(*e*) *Stock nitrate solution.* Weigh and dissolve 7.218 g of KNO_3 in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark. Preserve with 2 ml of chloroform per litre. In this solution 1.0 ml=1.00 mg of NO_3-N. This solution is stable for 6 months.

(*f*) *Standard nitrate solution.* Dilute 10.00 ml of the stock nitrate solution to 1 litre with distilled water. In this solution 1.0 ml=0.01 mg of NO_3-N.

(*g*) *Stock nitrite solution.* Weigh and dissolve 6.072 KNO_2 in distilled water. Transfer if to a 1-litre volumetric flask, and dilute to the mark. Preserve with 2 ml of chloroform and refrigerate. In this solution 1.0 ml=1.00 mg of NO_2-N.

(*h*) *Standard nitrite solution.* Dilute 10.0 ml of stock nitrite solution to 1 litre with distilled water. In this solution 1.0 ml=0.01 mg of NO_2—N.

Preparation of standards. Using the standard nitrate solution it becomes possible to prepare the following in 100-ml volumetrics.

ml of nitrate standard/100 ml of solution	*Conc. (mg of NO_3-N/litre)*
0.00	0.0
0.05	0.5
0.10	1.0
0.20	2.0
0.50	5.0
1.00	10.0

Standardization of the spectrophotometer

(*a*) Set monochrometer to 540 nm.

(*b*) Blank and zero the instrument.

(*c*) Add 75.0 ml of stock ammonium chloride-EDTA solution to 25.0 ml of each standard mix.

(*d*) Pour the sample into the activated column ; the flow rate must be 7 to 10 ml/min.

(*e*) Reject the first 25 ml to avoid cross-contamination. Collect the remainder.

(*f*) Add 2.0 ml of the sulfanilimide ; N(l-napthyl)-ethylene-diamine dihydrochloride color reagent to the collected standard.

(*g*) Add 10 minutes for color development. After the color gets developed, the sample should be analyzed on the spectrophotometer.

(*h*) Record the absorbance versus concentration of each standard and plot this data to obtain the standard nitrate curve.

(*i*) If nitrite data are desired, a similar curve is prepared by using diluted nitrite standard.

Analysis of samples. The analysis of samples is done exactly at the procedure for the standards. In other words, a 25-ml sample

is added to 75 ml of ammonium chloride-EDTA solution and run through the column. The sample is then made to react with the color reagent and analyzed, and the concentration could be known from the standard curve. In these cases, however, it has been advisable to blank and zero the instrument and then keep a portion of the sample in a cuvette with no reagents added. The absorbance given by this sample, if significant, must then be subtracted from the absorbance given by the samples reacted with the chromogenic reagent. This will compensate for any background color due to the sample.

Turbidity removal. Either of the following procedures may be used.

(*a*) Filter the sample through a glass-fiber filter or a 0.45 μm membrane filter.

(*b*) Add 1 ml of the zinc sulfate solution (number 2 under reagents) to 100 ml of sample and mix. To this add 0.5 ml of 6 N NaOH to get a pH of 10.5. Allow the sample to stand 5 minutes and filter.

Oil and grease removal. Filter 100 ml of the sample and adjust the pH to 2 by adding concentrated HCl. Add the sample to a separatory funnel, add 25 ml of chloroform, allow the sample to layer, and draw off the chloroform/oil fraction. Repeat this extraction twice.

pH adjustment. If the pH has been below 5 or above 9, it becomes necessary to adjust the pH to between 5 and 9 with either concentrated HCl or concentrated H_2SO_4; the pH may also be adjusted by using a base like concentrated NH_4OH. Adjustment of pH must be accomplished before adding the ammonium chloride—EDTA solution.

ORTHOPHOSPHATE (MODIFIED USGS METHOD)

This method could be used for the analysis of drinking water, groundwater, surface and marine waters, and domestic and industrial wastewater. The orthophosphate is made to react with an appropriate

chromogenic reagent and analyzed spectrophotometrically. In the case of deep-ocean-water analysis, where the phosphate has been present in low concentrations, a light path longer than that available with the common Spec 20 may be necessary. In all other samples the common 1-mm light path must suffice.

Preparation of reagents and standards

(*a*) *Ammonium molybdate solution.* Weigh and dissolve 15 g of ammonium molybdate $(NH_4)_6\ MO_7.4H_2O$ in distilled water ; transfer to a 500-ml volumetric flask and dilute to the mark.

(*b*) *Sulfuric acid solution.*

(*c*) *Ascorbic acid solution.* Weigh and dissolve 27 g of ascorbic acid in 500 ml of distilled water.

(*d*) *Potassium antimonyl-tartrate solution.* Weigh and dissolve 0.34 g of potassium antimonyl tartrate in distilled water, transfer to a 250-ml volumetric flask, and dilute to the mark.

(*e*) *Mixed reagent.* This solution could be prepared immediately prior to the actual analysis. Mix 100 ml of ammonium molybdate, 250 ml of sulfuric acid, and 50 ml of the potassium antimonyl tartrate solutions. This quantity has been suitable for the analysis of 50 samples.

(*f*) *Stock phosphate solution 1.* Weigh and dissolve 4.986 g of anhydrous KH_2PO_4 in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark. Add 1 ml of chloroform as a preservative and store in a dark bottle. In this solution 1.00 ml=36 μg at PO_4.

(*g*) *Stock phosphate solution 2.* Dilute 10.0 ml of this solution to 1 litre, preserve with 1 ml of chloroform, and store in a dark bottle. In this solution 3.6 μg-at PO_4/litre (in a 100-ml sample).

(*h*) To prepare the top standard (most highly concentrated standard), dilute 50 ml of stock phosphate solution 2 to 1 litre with distilled water. This solution is equal to 18.0 μg-at PO_4/litre.

(*i*) *By a series of dilutions from this solution, prepare 100 ml of the following standards.* 13.5 μg-at PO_4/litre : 9 μg-at PO_4/litre ;

4.5 μg-at PO_4/litre ; 2.25 μg-at PO_4/litre ; 1.12 μg-at PO_4/litre, and 0.56 μg-at PO_4/litre.

Standardization of the spectrophotometer

(*a*) Set the monochrometer at 885 nm (in the case of the Spectronic 20, it becomes necessary to use a red filter and the appropriate phototube to work at this wavelength).

(*b*) Blank and zero the instrument.

(*c*) To 100 ml of each standard, add exactly 10.00 ml of mixed reagent and mix. Allow the color to develop for 5 minutes.

(*d*) Keep it in a cuvette and analyze on the spectrophotometer.

(*e*) Observe the concentration and absorbance of each standard and plot these data to obtain the standard PO_4 curve.

Analysis of samples. A 100-ml portion of each sample is made to react with the mixed reagent and the absorbance determined. The concentration is then known from the standard curve. It is generally also advisable to blank and zero the instrument and then record the absorbance of each sample with no reagent added in order to compensate for any background color due to the sample (see NO_2-NO_3 method).

Detergent Analysis (standard methods) : modified

The most widely used method of detergent analysis has been the *methylene blue process*. This method depends on the formation of a blue-colored solution, when the methylene blue reacts with the synthetic detergents, commonly called *syndets*. The syndet-methylene blue has been soluble in chloroform ($CHCl_3$) and insoluble in water, while the methylene in $CHCl_3$ and soluble in water. Thus the syndet is combined with methylene blue, extracted from the water sample into the chloroform, and analyzed spectrophotometrically.

One problem encountered in this analysis has been that many naturally occurring substances also form chloroform-soluble substances with the methylene blue. Both organic and inorganic materials are known to react and yield either positive and/or negative interferences. Therefore, when analyzing raw water samples,

additional methods may have to be employed to remove these substances prior to initiating the analysis.

Reagents

(*a*) *Standard syndet stock solution.* Weigh and dissolve 1.00 g of syndet in distilled water, transfer to a 1-litre volumetric flask, and dilute to the mark. This solution 1 mg/ml.

(*i*) From this stock solution, by a series of dilutions, prepare 1 litre of the following standard solutions : 0.75 mg/ml, 0 50 mg/ml, 0.25 mg/ml, 0.125 mg/ml, 0.062 mg/ml, and 0.31 mg/ml.

(*ii*) These standards could be analyzed by the method given below, the absorbance determined, and the standard curve plotted.

(*a*) *Aqueous phenolpthalein indicator.*

(*c*) 1 N NaOH.

(*d*) 1 N H_2SO_4.

(*e*) Chloroform ($CHCl_3$)

(*f*) *Methylene blue reagent.* Weigh and dissolve 0.1 g of methylene blue in 100 ml of distilled water. Transfer 30 ml of this solution to a 1-litre volumetric flask and add 500 ml of concentrated H_2SO_4 and 50 g of $NaH_2PO_4.H_2O$. Mix until dissolved and dilute to the mark with distilled water.

(*g*) *Wash solution.* Keep 6.8 ml of concentrated H_2SO_4 with 500 ml of distilled water in a 1-litre volumetric flask. Dissolve 50 g of $NaH_2PO_4.H_2O$ in distilled water and add this solution to the volumetric flask. Dilute to the mark with distilled water.

Procedure

(*i*) Transfer 100 ml of sample (or standard if the curve is to be prepared) in a beaker.

(*ii*) Using phenolpthalein as the indicator, made the sample basic with 1 N NaOH.

(*iii*) Acidify with 1 N H_2SO_4.

(*iv*) Keep each sample and/or standard in a separatory funnel. To this add 10 ml of $CHCl_3$ and 25 ml of methylene blue. Shake for 30 seconds ; release the pressure and allow to separate.

(*v*) Draw off the $CHCl_3$ layer (bottom layer) into another separatory funnel and, in the first separatory funnel, repeat the extraction using 10 ml of $CHCl_3$, three times. If the extraction is repeated, $CHCl_3$ is added but not methylene blue. If the blue color in the aqueous phase disappears or becomes faint, however, 25 ml of methylene blue could be added.

(*vi*) After each extraction the $CHCl_3$ layer has been drawn off into the second separatory funnel.

(*vii*) After all extractions have been carried out add 50 ml of the wash solution to the second funnel and shake for 30 seconds ; allow to settle and draw off the chloroform layer through glass wool, into a 100-ml volumetric flask.

(*viii*) Repeat the washing twice with 10 ml of chloroform added each time and draw this material off into the 100 ml volumetric flask. Dilute to the mark with chloroform and mix.

(*ix*) Find out the absorbance of each sample (standard) at 652 nm against a chloroform blank.

(*x*) The standards have been plotted and a standard curve may be prepared.

(*xi*) The concentrations of the samples are then found out from the standard curve.

TRACE METAL ANALYSIS

Trace metals in water, tissue, and sediment samples are commonly estimated by either visible spectrophotometry or by atomic-absorption spectrophotometry. Recently, the majority of these analyses have been undertaken by atomic absorption spectrophoto-

metry, because of its greater sensitivity and case of analysis. The methods given here are for the atomic-absorption spectrophotometer.

Water to be examined for the presence of trace metals could generally be analyzed directly. In some cases the metal may have to get concentrated into a smaller volume by extraction into an appropriate solvent prior to analysis. In either case, the atomic absorption could be standardized by running a series of standards prior to the analysis of the samples.

Trace Metals (in sediments and tissues). In the analysis of sediments and tissues, the metal must first be extracted from this material priod to analysis. The tissue or sediment has been dried and the dry weight determined. The material is then refluxed in 100 ml of either 1 N HCR or 1 N HNO_3 for 1 hour. This extraction has been generally sufficient to remove all the acid-extractable metal and place it in solution.

A standard curve has to prepared for the particular metals of interest. The concentration of the standards is generally given in mg/ml of solvent. After the refluxing gets completed, the supernatent could be analyzed on the atomic-absorption spectrophotometer, and the data are obtained in mg/ml from the standard curve. As the data must be equated to the original sample (sediment, tissue, sludge), the percentage of the particular metal by weight of the total sample must be calculated. This is accomplished by using the the following equation :

$$\frac{\text{mg/ml of metal}}{\text{total wt of sample}} \times 100 = \%\ \text{wt of metal}$$

It has been to be noted that highly volatile metals, like mercury, cannot be refluxed without danger of loss. In these cases the atomic-absorption spectrophotometer could be operated with an attachment that will enable the total sample to be analyzed without the reflux step.

In all cases the manufacturer's instructions must be consulted prior to performing the analysis. In addition, it is to be noted that

the data could be determined in terms of ppm, ppb, mg/ml, or percent by weight, depending upon the units used in the preparation of the standard curve.

EVALUATION OF IMPURE WATER

The quality of water is judged according to five broad categories of constituents or characteristics.

1. *Physical properties.* Color ; odor ; temperature ; turbidity ; suspended solids.

2. *Microbiological organisms.* Coliform organisms ; fecal coliforms.

3. *Inorganic chemicals.* Alkalinity : dissolved oxygen ; pH ; total dissolved solids ; hardness ; and about 20 specific inorganic ions.

4. *Organic chemicals.* Carbon-chloroform extract (CCE) ; oils and greases ; phenols ; cyanide ; several individual pesticides.

5. *Radioactivity.* Radium-226 ; strontium-90 ; gross beta emitters.

6. *Biochemical oxygen demand (BOD) and chemical oxygen demand (COD).*

Standardized tests for determining all these constituents or properties have been devised.

Water used for drinking, cooking, and food processing as well as for swimming should have no odor and no color, and essentially no turbidity. The temperature does not affect safety to humans (within limits, of course), but thermal polution causes one environmental problem.

Normally the bacteria dwelling in the human intestinal tract have been harmless. However they serve as useful indicator organisms. If they are found in a water supply, the water has been contaminated by fecal matter and possibly, therefore, by disease-causing bacteria. Some viruses may also be present, and fecally contaminated water may be able to causes infections hepatitis.

The substances or properties under the category of inorganic chemicals need a number of specific measurements, some of which overlap. Dissolved solids, for example, include not only any inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates, and sometimes nitrates of sodium, potassium, and traces of calcium, magnesium, iron, and other metal ions but also any non-volatile organic substances which are solids at room temperature. Some dissolved solids make the water alkaline. Some are responsible for the hardness of water (the salts of calcium, magnesium, or iron). Some are poisons or provoke allergic reactions if present at excessive levels. The pH of water is regarded as a measure of its acidity. The deficiency or complete absence of dissolved oxygen makes the water a poor habitat for fish and other aquatic life, and when oxygen is absent the water more easily develops smelly products from the anaerobic (without-oxygen) decomposition of organic or microbiological contaminants. Too much oxygen in the water tends to increase the corrosion of metal water pipes and the machinery used by industry for cooling purposes.

The CCE level of water may be defined as the concentration of any substance(s) removed by a special chloroform-soluble, carbon-filter extract method. These include oily substances, organic solvents, paint materials, and many other industrial, organic wastes that are not necessarily degraded by bacteria. At a CCE value of 0.2 milligram/litre [200 parts per billion (ppb) CCE], the water generally is having a noticeably bad taste and odor. At sites well removed from industries, the CCE value is less than 0.04 milligram/litre (40 ppb).

Radioactive substances may be able to enter surface water and groundwater by natural causes or because of human activities. Many springs and deep wells pick up radioactivity from minerals through which their waters seep and percolate. The testing of nuclear devices in the atmosphere has produced fallout that has added radioactive substance—particularly strontium-90, cesium-137, and iodine-131—to water supplies. The third source of radioactive contaminants is the civilian nuclear power industry.

Biochemical oxygen demand (BOD) has been a standardized measurement of the amount of oxygen that would be required by microorganisms to cause the decomposition of certain organic and inorganic matter in the water. The measurement is done under standardized conditions (*e g.*, at 20°C and 5 days to allow the decomposition to take place). The result is called the 5-day BOD and is expressed in milligrams of oxygen per litre of water. BOD is not a pollutant but an indicator. It measures no particular substance but a family—any substance that microorganisms can consume (using oxygen as they do) or any material attacked under the conditions of the test. The substances decomposed in the test may be food used by the microorganisms or certain chemicals that are readily attacked by oxygen, perhaps with the aid of enzymes released by the microorganisms. These chemicals include sulphites and sulphides (from paper mills), ferrous iron, and some easily oxidized compounds. Many organics, however, make no contribution to the BOD but still render the water unfit for human use. BOD values of several hundred milligrams per litre characterize "strong" sewage. For "excellent" drinking water the 5-day BOD, on a monthly average, should be in the range of 0.75—1.5 milligrams/litre. BOD values are important when they signify that the oxygen supply dissolved in the water will be so greatly reduced that desirable fish no longer can survive or when they signify that conditions for the propagation of dangerous bacteria exist.

The chemical oxygen demand (COD) has been a measure of the concentration in a water supply of substances that can get attacked by a strong chemical oxidizing agent in a standardized analysis. (Dichromate oxidation is commonly used). The results of the analysis are usually expressed in terms of the amount of oxygen that would be needed (in principle, because oxygen is not itself used) to oxidize the contaminants to the same final products obtained with the standardized analysis. COD values do not get necessarily correlated with BOD values. Textile wastes, paper mill wastes, and other wastes with high levels of cellulose have COD values considerably higher than their BOD values as cellulose is not

readily attacked in the BOD test. Distillery and refinery wastes often have BODs higher than CODs unless the COD measurement is specially modified. In the nature of the two tests, the BOD of a given water supply is able to decrease faster than its COD.

A comparative account of BOD and COD is given in Table 5.1.

Table 5.1. Comparison of BOD and COD.

Biological Oxygen Demand (BOD)	*Chemical Oxygen Demand (COD)*
1. It may be defined as the amount of oxygen used for biochemical oxidation by microorganisms in a unit volume of water. This test has been developed for five days at 20°C.	It may be defined as the amount of oxygen required by organic matter in a sample of water for its oxidation by a strong chemical oxidant and is expressed as ppm of oxygen taken from a solution of potassium dichromate in two hours.
2. As BOD value approximates the amount of oxidizable organic matter, it is therefore, used as a measure of degree of water pollution and waste strength.	2. This value has been a poor measure of strength of organic matter as oxygen also get consumed in the oxidation of inorganic matter such as nitrates, sulphates, reduced metal ions, and also that some organic materials like benzene, pyridine and few other cyclic organic compounds do not get oxidized by this test.
3. BOD values have been useful in process design and loading	3. It has been a very important parameter in management and

calculations, measure of treatment efficiency and operation, stream pollution control and in evaluating self-purification capacity of a stream.	design of the treatment plants due to its rapidity in determination. Values are taken as basis for calculation of efficiency of treatment plants and also figure in the standards for discharging industrial domestic effluents in various kinds of waters.
4. Types of microorganisms, pH, presence of toxins, some reduced mineral matter and nitrification process have been the important factors that influence the BOD test.	4. Presence of toxins and other such unfavourable conditions for the growth of microorganisms are not able to affect COD values.

7

Classification of Water Pollutants

INTRODUCTION

The signs of water pollution have been obvious to even the most casual observer. Drinking water tastes bad ; masses of aquatic weeds are growing unchecked in many bodies of water ; ocean beaches, rivers, and lakes emit disgusting odors ; game and commercial fish are decreasing in numbers, add the meat of some of them is tainted ; and oil can be seen floating on the surface of some bodies of water or deposited as scum on beaches. The diversity of these signs snd effects reveals the complexity of the problem. The origins of these problems could be attributed to many sources and types of pollutants. To aid in a systematic discussion of water pollutants, they will be classified into 9 categories given below. Each category is discussed in this chapter and then some specific pollutants have been studied in more detail in the following chapters.

1. Oxygen-demanding wastes
2. Disease-causing agents
3. Plant nutrients
4. Synthetic organic compounds
5. Oil
6. Inorganic chemicals and mineral substances
7. Sediments

8. Radioactive materials
9. Heat.

Some overlap between categories has been unavoidable, because some wastes are having more than one pollutant. Raw sewage, for example, has been an oxygen-demanding waste which may be having disease-causing agents and plant nutrients.

1. Oxygen-Demanding Wastes

Dissolved oxygen has been a fundamental requirement of life for the plant and animal population in any given body of water. Their survival is dependent upon the ability of the water to maintain certain minimal concentrations of this vital substance.

Fish need the highest levels, invertebrates lower levels, and bacteria the least. For a diversified warm-water biota, including game fish, the dissolved oxygen (DO) concentrations must be at least 5 mg/*l* (5 ppm). For a cold-water biota, DO concentrations at or near saturation values have been desirable. The minimum level must be no lower than 6 ppm. The amount of DO at saturation varies with water temperature and altitude. At 20°C and 1 atmosphere of pressure, the value is 9 ppm. High mountain lakes may be having 20-40% less DO than similar lakes at sea level.

A body of water has been classified as polluted when the DO concentration drops below the level necessary for sustaining a normal biota for that water. The primary cause of water deoxygenation has been the presence of substances collectively called *oxygen-demanding wastes.* These are substances easily broken down or decayed by bacterial activity in the presence of oxygen. The available dissolved oxygen has been consumed by bacterial activity, and thus, the presence of such materials quickly gives rise to depletion of dissolved oxygen.

Oxygen-demanding wastes are primarily organic materials that are oxidized by bacteria to carbon dioxide and water. These substances have been deleterious because their decomposition gives rise to oxygen depletion in both freshwater and marine systems. They

also produce unaesthetic odors, endanger water supplies, and decrease the recreational value of waterways.

A common measurement of this type of pollution involves the amount of molecular oxygen needed to decompose the material through aerobic biochemical action. The standard test has been the 5-day BOD (biochemical oxygen demand) test, in which the amount of dissolved oxygen required for oxidation over a 5-day period has been measured, the results being expressed in milligrams of oxygen per litre (mg/l). When the amount of sewage discharged has been relatively minor, a river will not become badly polluted as biological degradation will soon remove most of the wastes; however, strong sewage or other oxygen-demanding wastes from industry or agriculture can lead to the depletion of the dissolved oxygen in the water. "Septic" conditions are said to be present when the dissolved oxygen level is very low. Fish and other aquatic life near dissolved oxygen for survival and the DO (dissolved oxygen) level should normally be at least 5 mg/l (higher in cold water, especially in spawning areas, which require at least 7 mg/l). The DO level of water saturated with oxygen is 9.2 mg/l at 20°C (68°F). If there has been insufficient dissolved oxygen for degradation of organic materials, oxygen may be obtained from dissolved nitrates and sulphates, with the accompanying production of disagreeable-smelling gases such as H_2S. If ample dissolved oxygen, is available, microorganisms are able to oxidize nitrogen compounds and certain inorganic compounds such as ferrous salts, sulphides, and sulphites. COD (chemical oxygen demand) tests have been using strong oxidizing compounds, like potassium permanganate, to oxidize even some materials that have been not biologically degradable; COD values will be larger than BOD values.

Sewage and other oxygen demanding wastes have been classified as water pollutants because their degradation leads to oxygen depletion, which affects (and even kills) fish and other aquatic life; because they cause annoying odors; because they impair domestic and livestock water supplies by affecting taste, odors, and colors and

because they may give rise to scum and solids that make water unfit for recreational use.

Although some inorganic substances occur in this category, most oxygen-demanding wastes are organic compounds. Pollutants in this category typically come from such sources as sewage, both domestic and animal; industrial wastes from food processing plants ; wastes from paper mill activities ; tanning operation by-products ; and effluent from slaughterhouses and meat-packing plants. The effects of adding these materials to water have been a function of the amount of water available for dilution. For this reason, it has been not surprising to find that low DO problems have been especially common in late summer and early fall, when water levels are normally low.

Most compounds involved in this type of pollution have carbon as their most abundant element. One reaction they undergo, with bacterial help, is the oxidation of carbon to CO_2.

$$C + O_2 \rightarrow CO_2$$

In this reaction 32 grams of oxygen are needed to oxidize 12 grams of carbon. The carbon can thus be thought of as demanding nearly three times its weight in oxygen for the reaction to take place. On this basis, 9 ppm of oxygen would be required to react with approximately 3 ppm of dissolved carbon. This amounts to a reaction between the dissolved oxygen from a gallon of water and a small drop of oil. It becomes easy to see how waters can quickly be depleted of dissolved oxygen.

As oxygen-demanding wastes rapidly deplete the DO of water, it has been important to be able to estimate the amount of these pollutants in a given body of water. The biochemical oxygen demand (BOD) of water has been a quantity related to the amount of wastes present. In a water sample, the BOD indicates the amount of dissolved oxygen used up during the oxidation of oxygen-demanding wastes. It could be found out by incubating a sample of water for five days at 20°C. The amount of oxygen consumed (BOD) could be

found out by chemical determination of the DO concentration of the water before and after incubation.

A BOD of 1 ppm has been characteristic of nearly pure water. Water has been regarded fairly pure with a BOD of 3 ppm, and of doubtful purity when the BOD value reaches 5 ppm. Public health authorities object to run-off entering streams if the BOD of the run-off exceeds 20 ppm. A comparison of these BOD levels with the range of values characteristic of the sources given in Table 7.1 reveals the seriousness of the problem. Obviously, the pollutants

Table 7.1. Characteristic BOD Levels

Source	*BOD Range (ppm)*
Untreated municipal sewage	100-400
Run-off from barnyards and feed lots	100-10,000
Food processing wastes	100-10,000

of Table 7.1 must be highly diluted upon entering water if the dissolved oxygen is not to be rapidly and completely depleted. The problem has been especially critical for bodies of water already low in dissolved oxygen.

An interesting way to point out the magnitude of the oxygen-demanding waste problem has been to equate the BOD of the total daily nationwide wastes from specific sources to the number of humans required to produce daily waste with an equivalent BOD.

The disappearance of plant and animal life is an obvious result of the oxygen depletion of water, This occurs by a direct killing effect or because of migrations to other areas. A less obvious but important result has been a shift in water conditions from those favoring aerobic (oxygen required) activity to those that support anaerobic (oxygen not needed) activity. This occurs when the oxygen levels become so low that the aerobic microorganisms are destroyed or driven away and anaerobic ones take their place. The products of decomposition following these different pathways have been quite different, as shown in Table 7.2.

Methane (CH_4) has been odorless and flammable ; amines are having a fishy smell ; hydrogen sulfide is bad smelling and toxic ; and some phosphorus compounds have unpleasant odors. When

Table 7.2. Comparison of Decomposition end Products Under Differing Conditions

Aerobic conditions	*Anaerobic conditions*
$C \rightarrow CO_2$	$C \rightarrow CH_4$
$N \rightarrow NH_3 + HNO_3$	$N \rightarrow NH_3$ + amines
$S \rightarrow H_2SO_4$	$S \rightarrow H_2S$
$P \rightarrow H_3PO_4$	$P \rightarrow PH_3$ and phosphorus compounds

these contributions are added to the odor of decaying fish or algae, it becomes apparent that a shift from aerobic to anaerobic conditions of decomposition is not one which is favored by users of fresh air.

2. Disease-Causing Agents

In any community it must be regarded that a certain number of individuals will get diseased and thus capable of contaminating the water with various *infectious agents*. In addition, hospitals dispose of waste products into waterways and groundwater systems. Unfortunately, the identification of specific infectious agents in a water supply needs the analysis of vast numbers of samples by time-consuming and sophisticated methods. Generally, therefore, routine monitoring of water supplies employs the *MPN (Most Probable Number) Method*. This analysis determines the most probable number of intestinal bacteria that occur in a given water sample. Although these organisms have been not pathogenic, their concentration is a fairly reliable indicator of possible pathogenic contamination of a given water supply.

Water has been a potential carrier of pathogenic micro-organisms and can endanger health and life. The pathogens most frequently transmitted through water have been those responsible for infections of the intestinal tract (typhoid and para-typhoid fevers, dysentery, and cholera) and those responsible for polio and infectious hepatitis. Historically, the prevention of water-borne diseases was the primary reason for pollution control in water. Modern disinfection techniques have greatly reduced this danger. This is not true for some large parts of the world, where, for

example, cholera epidemics are still common. The fact that such disease-causing agents are under control must not result in a sense of false security. The occurrence of a polluted water supply leading to an outbreak of disease is always a possibility. The responsible organisms are present in the feces or urine of infected people and are ultimately discharged into a water supply.

Even though it might seem desirable, a direct check for these organisms is not routinely performed on water supplies. Instead, indirect methods are used for the following reasons. Pathogens have been likely to gain entrance into water only sporadically, and once in the water they do not survive for long periods of time. Consequently ; their presence could easily be missed by routine sampling. Laboratory procedures are likely to fail to detect pathogens that are present in very small numbers. Also it requires 24 hours or longer to get results from a laboratory examination. If pathogens were found in a water sample, it is likely that many people already would have used the water and be subject to infection.

An indicator organism, Coliform bacteria, has been forming the basis of the indirect method commonly used. These benign organisms live in the large intestine and absorb nutrients from their surroundings, They incite no diseases and have been always present in feces. Their presence in water is an indication of fecal discharge into the water. These organisms have been present in large numbers, making their detection quite easy. It is estimated that billions are excreted by an average person per day. These natural inhabitants of the human bowel do not find environmental conditions in natural waters suitable for multiplication and, in fact, they begin to die rapidly. Their presence in water samples therefore allows a rough diagnosis to be made of the time elapsed since fecal contamination took place. If fecal contamination is recent, it can be regarded that pathogenic organisms may be present along with the harmless Coliform bacteria. The absence of Coliform bacteria means that recent intestinal discharges are not present in the water, and presumably the water is free of pathogens.

It should be mentioned that bacteria responsible for the decomposition of the organic constituents of sewage are having no sanitary or public health significance. They do not occur in the intestinal tracts of man or animals, and they have been not pathogenic.

Waste water released from municipalities, sanitoria, tanning and slaughtering plants, and boats may be sources of bacteria or other microorganisms which are capable of producing disease in men and animals, including livestock. Any fair-sized community at any given time has been likely to have *some* persons who are diseased so that disease microorganisms are almost always present in sewage.

There have been several types of human infections, not all of which are transmissible through water (see Table 7.3). Many of

Table 7.3. Examples of Human Infections

A. Animal infections that are of public health importance because they are transmissible to man.

1. Tetanus from horses and cattle transmitted by inoculation or contact with animal feces.
2. Bubonic plague from wild rodents by insect (flea) bite.
3. Anthrax from herbivorous animals by direct contact.
4. Rabies from dogs, bats, etc., by bites.
5. Bovine tuberculosis from cattle through ingestion or airborne transmission.
6. Jungle yellow fever from monkeys through mosquito bites.
7. Several types of encephalitis from birds and fowl through mosquito bites.
8. Trichinosis from swine through ingestion.

B. Primarily human infections in which the infective agent has a certain period of extrahuman residence before transmission.

1. Schistosomiasis ("snail fever") from water from snails.
2. Urban yellow fever from mosquitoes.
3. Hookworm from soil by skin penetration.
4. Malaria (also a mosquito infection) from mosquitoes.
5. Typhus from lice.

C. Infections that persist or multiply in the external environment and are transmissible from man to man.

1. Cholera, typhoid fever, bacillary dysentery, poliomyelitis, and infectious hepatitis from water and food through ingestion.
2. Staphylococcal and streptococcal diseases from food, air, and the proximate environment through contact and inhalation.
3. Smallpox from air, dust, and the proximate environment through inhalation.
4. Coxsackie and ECHO virus diseases from water through ingestion.

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the diseases whose epidemics recurrently decimate human populations get transmitted by water, however, cholera and typhoid being important examples.

The identification of pathogens in water needs very large samples and many sophisticated techniques and is too time-consuming and expensive for routine pollution tests. The standard method involves determination of the most probable number (MPN) of coliform organisms in the water sample. Coliform bacteria like *Escherichia coli* have been normal inhabitants of human and animal intestines, and the daily per capita excretion in human feces may number from 125 to 400 billion. These organisms will get reduced in number in the water by death in the non-normal environment and by their removal and destruction in waste-water and drinking-water treatment processes. Although coliform organisms have been not pathogens and are not affected by the water environment in exactly the same manner as pathogens, their existence and density has proved to be a fairly reliable indicator of the adequacy of treatment for reducing pathogens, and coliform tests are therefore widely used.

3. Plant Nutrients

Nutrients are an important limiting factor in the growth of all plants. With all other factors equal, the rate and profuseness of plant growth are proportional to the amount of nutrient available.

Plant nutrients (phosphorus and nitrogen) enter fresh and marine systems and lead to or intensify eutrophication of these systems. These nutrients tend to accumulate in groundwater since it is out of the euphotic zone. As the groundwater moves laterally and reaches the surface waters, these materials add to the nutrient levels already present.

Plant nutrients like nitrogen and phosphorus are able to stimulate the growth of aquatic plants, which get interfere with water uses and later decay to produce disagreeable odors and add to the BOD of the water. Excess algal growths all of particular concern because they cause low dissolved oxygen levels and create treatment problems for municipalities and industries, in addition to interfering with recreational uses. Plant nutrient concentrations have been generally expressed in ppm by weight or milligrams per litre (mg/l), which have been essentially equal in water. In general it has been the concentration of soluble inorganic nitrogen and phosphorus that has been of importance and care must be taken in expressing the levels to distinguish between elements and compounds, such as between phosphorus and phosphates.

The enrichment of water with nutrients is a naturally occurring biological process called *eutrophication.* The term comes from two Greek words meaning "well nourised." This enrichment leads to other slow processes collectively referred to as *natural aging of lakes.* In some pollution articles, the term eutrophication includes both nutrient enrichment and lake-aging processes. The existence of peat and muck soils and deposits of coal and oil are proof that eutrophication and aging have been taken place in the past. The steps in eutrophication and aging of a lake have been as follows :

1. Streams from a drainage basin gradually bring soil and nutrients to a newly formed lake, increasing the fertility of the lake water.

2. The increased fertility leads to an accumulating growth of aquatic organisms, both plant and animal.

3. As living matter increases and organic deposits pile up on the bottom of the lake, it becomes more shallow, warmer, and richer in nutrients.
4. Plants take root at the bottom and gradually occupy more and more of the space. Their remains accelerate the filling of the basin.
5. The lake gradually becomes a marsh and finally a field or forest as it has been overrun by vegetation.

The time needed for this aging process to be completed could be measured in thousands of years. The actual time depends upon the size and mineral content of the basin, and the climate.

In a strict sense, eutrophication is not regarded to be a matter of water pollution, because it takes place naturally and some necessary or aquatic life could not survive. It does become a pollution problem when man, through his activities, accelerates the process and the resultant aging of lakes. The high concentration of nutrients resulting when natural and man-caused contributions combine produces rapid plant growth which first becomes apparent as algae blooms. The term *bloom* has been used when the concentration of individual species exceeds 500 individuals per milliliter of water.

The algae blooms and large amounts of other aquatic weeds create numerous problems. The excessive plant growth has been generally unsightly and interferes with recreational uses of water. The blooms are also contributing unpleasant tastes and odors to water and become consumers of dissolved oxygen upon dying and decaying. This latter process gives rise to the deoxygenation effects previously discussed.

The growth of green plants, including algae, needs the availability of from fifteen to twenty elements which, together with their chemical symbols, have been given in Table 7.4. The relative amounts of these elements needed forplant growth depend upon the species involved. The amounts needed for the growth of three

typical nuisance algae are given in Table 7.5. The values have been based on chemical analyses of the dried algae.

Table 7.4. Elements Necessary for Plant Growth.

Carbon (C)	Magnesium (Mg)	Boron (B)
Hydrogen (H)	Calcium (Ca)	Vanadium (V)
Oxygen (O)	Sodium (Na)	Chlorine (Cl)
Nitrogen (N)	Iron (Fe)	Molybdenum (Mo)
Phosphorus (P)	Manganese (Mn)	Cobalt (Co)
Sulfur (S)	Copper (Cu)	Silicon (Si)
Potassium (K)	Zinc (Zn)	

It is apparent that the major element needed for growth of these algae is carbon. Nearly 0.5 lbs. is needed to produce 1.0 lb. of dry Anabena algae. Nitrogen, potassium, and phosphorus follow in importance for theMicrocystis and Anabena algae.

Table 7.5 Chemical Composition of Three Nuisance Algae.

		Algae	
Element	*Microcystis*	*Anabena*	*Cladophora*
C	46.5 wt%	49.7 wt%	35.3 wt%
N	8.1	9.4	2.3
P	0.7	0.77	0.56
K	0.8	1.2	6.1
Ca	0.53	0.36	1.7
S	0.27	0.53	1.6
Fe	0.27	0.08	0.23
Mg	0.17	0.42	0.23
Na	0.04	0.18	0.18
Mn	0.03	0.008	0.10
Zn	0.005	0.000	0.001
Cu	0.004	0.007	0.019
B	0.0004		0.0085

Note. Hydrogen and oxygen constitute the major unreported portion of the analyses. These elements are abundantly available at all times as water, H_2O.

Most elements essential for plant growth have been available to the plant in amounts well in excess of the plant's needs. A few, however, have been present in amounts very close to the quantities required for plant growth. These may be used by the plant almost to the point of exhaustion. Considerable interest gets centered around these elements because they appear to behave as natural controls in preventing excessive plant growth. The growth of a plant will cease when the least available element gets depleted. Man's role in eutrophication appears to be one of increasing the amounts of these growth-limiting elements. Great changes in the availability of some elements in water have taken place through man's activities.

Many studies have been in progress in which relationships are being sought between concentrations of nutrients present in water and the needs of plants. Such research into the water chemistry of nutrient cycles has turned out to be a very complex problem because of the variability of aquatic systems. Typical problem areas have been as follows :

1. Chemical analyses of algae have not resulted in a definition of the limiting amounts of nutrients needed to support their growth. Partly this is because of the unique ability of algae to absorb large excesses of an element. This phenomenon is known as "luxury" uptake or consumption and takes place very rapidly when plentiful supplies of nutrients reach a growing body of algae. The excess element absorbed during this process readily gets released by the cells to supply growth needs at later times.
2. Different species of algae are having different minimum requirements for elements.
3. Different bodies of water are having different basic ratios of nutrients which depends on the geological surroundings of the water.
4. Many sources of nutrients are available and all must be taken into consideration. Some nutrients may be taken from the air and used directly. This means that factors

other than aqueous nutrients concentrations must be considered.

Results so far reveal that one key limiting reactant will not be found. The three elements studied in greatest detail, phosphorus, nitrogen, and carbon have all been found to be limiting reactants depending upon water conditions. Phosphorus could be limiting to algae growth in nutrient-poor lakes, but it may be present in excess in nutrient-rich lakes. It has been generally agreed that nitrogen has been a limiting nutrient in some lakes and in many or perhaps most estuarine and coastal waters. Carbon appears to be a limiting factor only under restricted circumstances such as those present in extremely eutrophic soft-water lakes.

Both nitrogen and phosphorus occur in small amounts in natural waters, but their concentrations get greatly increased by the activities of man. As much as 80% of the nitrogen and 75% of the phosphorus added to surface waters originate from man-made sources. Table 7.6 gives estimates of possible nutrient discharge (as P and N) into estuaries from a hypothetical community. The community has been made up of 10 million people and the nutrients are put into a river discharging 15,000 cubic feet of water per second into the estuaries. It is regarded that 20 volumes of seawater dilute each volume of discharged river water.

Table 7.6. Example of Possible Nutrient Discharges to Estuaries from Various Sources (Metric Tons Per Year)

	Nitrogen (N)	*Phosphorus (P)*
Sewage : population of 10 million, per capita generation 400 liters/day	6,000	15,000
River water : discharge 500 m^3/sec (approx. 15,000 cfs)	300	7
Subsurface seawater : 20 volumes of seawater mixing with each volume of river water	6,000	900
Storm-water runoff : 75 cm (30 inches) per year area	6,000	800

The dominant source of phosphorus has been seen to be sewage, whereas nitrogen in various forms has been supplied in nearly equal amounts by sewage treatment plants, storm-water run-off, and subsurface seawater.

The phosphorus content of domestic sewage is becoming a topic of concern. It is estimated that up to 70% of this comes from the use of household detergents, and it should be subject to rather easy control procedures. The elimination of phosphorus compounds from detergents has been discussed at great length at another place.

Algae growth needs many different nutrients like-carbon dioxide, nitrogen, phosphorus, iron, manganese, boron, cobalt, vitamins, hormones, etc. The elimination of any one of the essential nutrients would not allow algae growth but there is an active scientific controversy about which nutrients should be controlled. It is generally felt that control of nitrogen and phosphorus would be best but some scientists think that the availability of carbon is a much more important limitation, and the large amounts of phosphorus present in the sediments in lakes and rivers yield a vast reservoir available for the growth of algae. More research has been needed to establish, for example, whether or not CO_2 from air and rain has been sufficient to stimulate algae growth or whether CO_2 production by bacterial decomposition of organic matter is necessary. The most likely answer is probably that phosphorus is the limiting element in some bodies of water but not in others where it is present in large concentration.

Not much information is available about comparative natural and man-made sources of nutrient in waterways. The estimates made by Ferguson are reproduced in Table 7.7. Using the total streamflow and taking the minimum phosphorus tonnage from the table, he estimates the average concentration of phosphorus in waterways to be 0.26 ppm of which 0.08 ppm come from phosphates indetergents. Phosphate removal from detergents might be able to alleviate algae growth problems in some areas but not in all, and

the same has been reported to be true of phosphate removal from waste water by advanced treatment methods.

Table 7.7. Natural and Man-generated Sources of Nitrogen and Phosphorus. Data are in Thousands of Metric Tons per Year.

	Nitrogen	*Phosphorus*
Natural	470-1900	110-320
Man-generated	1810	310-460
Domestic sewage	605	175-200
Runoff from urban land	90	20
Runoff from cultivated land	925	50-175
Runoff from land on which animals are kept	190	75
Total	2280-3710	420-780

SYNTHETIC

4. Organic Chemicals

Organic chemicals can be considered to be any compound that contains one or more carbon atoms in its molecular structure. Organics that commonly enter waterways are pesticides, detergents, and hydrocarbons. The term *pesticide* may be applied to any material which is used to kill pests and covers insecticides, herbicides rodenticides, and fungicides.

The exotic organic chemicals include surfactants in detergents, pesticides, various industrial products, and the decomposition products of other organic compounds. Analysis of polluted waters reveal the presence of a wide variety of these compounds and many others have been probably not being detected. Concentrations are generally expressed in ppm by weight (equal to mg/*l*). Some of these compounds have been found to be toxic to fish at very low concentrations, such as 1 ppm phenol. Many are not biologically degradable, or are degraded only very slowly. As many new chemi-

cal compounds get introduced each year without much knowledge of their effects on natural ecosystems, there exists always a possibility that irreversible damage might get caused before scientists could be able to realize it.

Laundry *detergents*, a common constituent of wastewater, have been another organic contaminant. Detergents consist of two major components : a surfactant or sudsing agent and a series of builders. The surfactant lowers the surface tension of the wash water, concentrates, and is preferentially absorbed at the surface and thereby replaces the dirt. After the dirt has been removed (replaced by the surfactant) the surfactant could be removed in the rinse water. The builders isolate the common elements found in hard water (calcium and magnesium), which would tend to interfere with the action of the surfactant. The surfactant or sudsing agent can become a problem as it is not readily broken down by bacterial action and has a long residence time. Even in relatively low concentrations, it can cause water to form foam.

Most detergents manufactured in the early 1970s were composed of approximately 40% sodium tripolyphosphate, the "builder" component. It is calculated that such phosphorus-bearing builders account for one-half the total phosphate in most wastewaters. Due to this extremely high phosphorus concentration, these detergents are a major source of eutrophication in freshwater systems. In addition as detergents have been contributing a large amount of phosphorus to wastewater without a corresponding addition of nitrogen, a nitrogen/phorphorus imbalance will take place when this material enters either marine or fresh-water systems.

Hydrocarbons, in the form of gasoline and motor oil, although insoluble in water, have been carried from roadways and parking areas in rainwater runoff. Sumps (surface-water catchment basins) accept the water from these areas via a system of storm drains. From these basins the water and associated hydrocarbons percolate down into the water table. Some storm drains empty dtrectly into the nearest surface-water body, carrying the storm water and associated hydrocarbons directly into the waterway.

In addition to the elements mentioned above, analysis of water reveals the presence of a wide variety of other organic chemicals. Some of these compounds are known to be toxic at very low concentrations, while many are not biodegradable or break down very slowly.

Much more work is needed to determine the relationships to the environment of many of synthetic organic compounds. The following facts are known about them :

1. Some have been resistant to biochemical breakdown by naturat water bacteria or waste treatment processes and therefore persist for extended periods of time in water.
2. Some have been responsible for objectionable and offensive tastes, odors, and colors of some fish and shellfish taken from polluted water.
3. Some have been toxic to fish and other aquatic life when present in very low concentrations.

As the use of these compounds has been expanding so rapidly, it has been important that certain facts be determined. The distribution, fate, and potentially hazardous effects must be the topics of future research.

5. Oil

The production, distribution, and use of such large yearly quantities results in some oil contamination of the environment. Some of this contamination is accidental, some is not. A separate chapter has been devoted to a discussion of the problem of oil pollution.

6. Inorganic Chemicals and Mineral Substances

This category of water pollutants have been including inorganic salts, mineral acids, and finely divided metals or metal compounds. These substances enter natural waters because of activities in various smelting, metallurgical, and chemical industries ; mine drainage ; and various natural processes. The presence of these brings about

three general effects : the acidity, salinity, and toxicity of the water may be increased.

Inorganic chemicals of many types enter water from municipal and industrial waste waters and urban runoff. They are also measured in ppm by weight or mg/*l*. These pollutants are able to kill or injure fish and other aquatic life and they can interfere with the suitability or water for drinking or industrial use. Many of these inorganics are not only toxic but tend to concentrate in food chains.

A prominent example has been the occurrence of mercury in water. A number of industrial processes make use of mercury, some of which is eventually disposed of in waste-water effluents. It is now known, that anaerobic bacteria in bottom muds can convert inorganic mercury into methyl mercury (CH_3Hg^+), which can be concentrated in living things and lead to mercury posioning.

One potential pollutant arises in petroleum drilling, where brine gets discharged along with crude oil when the latter is pumped to the surface. In some places the brines have proved valuable sources of important minerals and elements, such as bromine, iodine, and magnesium.

Another very important problem, is acid mine drainage. On exposed coal mine surfaces, minerals, containing sulphur (most notably iron pyrite, FeS_2) come into contact with air and water, forming sulfuric acid that has been carried into streams by waters draining from the mines. This takes place from abandoned mines as well as operating mines and has been most pronounced in bituminous coal mines.

Acid mine drainage has been the primary source of pollutants that increase water acidity. This drainage adversely affects thousands of miles of streams and has been one of the most significant causes of water quality degradation in coal-producing areas. The actual pollutants present in mine drainage have been sulfuric acid (H_2SO_4) and soluble compounds of iron. These substances are formed because of a reaction between air, water, and pyrite (FeS_2) present

in coal seams. Certain types of bacteria have been involved in the reaction, but their role has been not completely understood. This reaction can occur in both underground and surface mines.

During mining operations in deep mines, the strata between the coal seam and the surface have been invariably disturbed. Fissures appear through which water drains into the mine from many surface areas. This water containing the harmful pollutants is eventually discharged into surface streams, either naturally or through man-made processes. Damaging mine drainage is formed in surface mines if the surface run-off water comes in contact with pyrite-containing coal.

About 60% of the mine drainage pollution problems originate in mines once worked but now abandoned.

At the present time, much effort has been directed toward either disallowing the formation of acid mine drainage or removing the pollutants by chemical treatment prior to releasing the discharge into natural waters. Three methods commonly used have been as follows :

(*a*) *Sealing of abandoned mines.* Sealing abandoned mines to disallow the entry of air or water helps to disallow the fundamental reactions involved in acid mine drainage formation by eliminating at least one of the required reactants. The inability to attain tight seals would be a problem with this method.

(*b*) *Drainage control.* Attempts are made to minimize the contact time between water and pyrite by quickly removing water from mines. It is difficult to gather the water from the many sources which are available to an underground mine. This problem has curtailed some of the effectiveness of this method.

(*c*) *Chemical treatment.* This method has been used in many active mines. The mine discharge has been sent to a nearby treatment plant where hydrated lime has been

added. This has been followed by an aeration of the water. The water has been then placed in large lagoons where the sludge, created by the process, settles to the bottom, and a clear overflow gets discharged into the natural waters. This process has been quite simple, but problems are created by the large amounts of iron-containing sludge that are formed. These materials causes disposal problems. Also, the use of lime generally leaves the water saturated with dissolved salts.

There has been still a great deal of research needed if the problems of acid mine drainage have been to be solved.

Coal mining has been not the only source of acidic water pollutants. Other types of mining make their contributions, as do various other industries. Large amounts of acid have been used to clean oxides and grease from metals. The used acids from these pickling operations have been becoming serious problems in some localized areas.

Due to the presence in solution of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions, the pH of most productive, fresh natural waters lies between 6.5 and 8.5. This natural buffer system makes it possible for small amounts of acid or base to dissolve in the waters without making appreciable changes in the pH. These ions also represent an indispensable reservoir for carbon needed by aquatic plants during photosynthesis. Such use of these ions by plants can influence the buffering capacity of water, as there is a decided limit on the rate at which CO_2 (the source of CO_3^{2-} and HCO_3^-) can be obtained from the atmosphere to replace that used by plants.

Large influxes of strong acid have been able to overwhelm this buffering ability of water and bring about drastic drops in pH values. The effects of these changes depend upon the magnitude of the pH drop involved. Some effects have been as follows :

(*a*) *Aquatic life destruction.* At pH levels below 4.0, all veretbrates, most invertebrates, and many microorganisms get

destroyed. Most higher plants are eliminated, leaving only a few algae and bacteria. Acid mine drainage is one of the primary causes of fish kills. Excessive precipitation increases the mine drainage output and compounds the problem. During high water seasons (winter and spring), the pH of the waters in some areas has been reported to be as low as 2.5.

(*b*) *Corrosion.* Water having a pH lower than 6 0 can bring about excessive corrosion of plumbing systems, boats, piers, and related structures.

(*c*) *Agricultural crop damage.* Acidity and alkalinity of irrigation water have been usually of little consequence over a pH range of 4.5—9.0, as the soil has been a buffered system. Problems may asise if the pH drops below 4.5. Such acidic water increases the solubility of such substances as Fe, Al, and Mg salts. These ions, at the resulting high concentrations, have been sometimes toxic to plants.

One mechanism by which fish and other aquatic animals get destroyed by acid pollution involves the equilibrium between CO_2, HCO_3^- and CO_3^{2-}. At low pH, HCO_3^- and CO_3^{2-} are both converted to CO_2 which dissolves in water. This excessive "free" CO_2 in the water interferes with the processes by which CO_2 gets eliminated from the animals.

Because of metabolic activity, CO_2 gets produced in the animal cells and moves by way of the blood to organs (gills) where it leaves the blood and diffuses into the water. An increase in external CO_2 slows the diffusion rate from the blood. The result has been an accumulation of CO_2 in the blood of the animal, with the result that less oxygen can be carried by the blood and the pH of the blood decreases. These conditions can eventually lead to the death of the animal.

Salinity of water has been not an uncommon observation. About 97% of the total water in the world occur in oceans and seas

in the form of salt water. It is common knowledge that such water is not suitable for consumption by man. The remaining 3% is classified as fresh water, but it can and does acquire salinity. The sources of salinity have been varied and include :

(a) *Industrial Effluents.* Inorganic salts form a major constituent of many industrial effluents. Salts are the products of acid-base neutralizations, many of which find use in various smelting, metallurgical, and chemical industries. Acid mine drainage can also cause salts to be formed.

(b) *Irrigation.* Water used in irrigation is able to dissolve large amounts of minerals as it percolates down through soil.

(c) *Salt Brines.* Occasionally, salt brines from mines or oil wells get released into normally fresh water.

(d) *Ocean Salt.* Large rivers normally does not allow salt water of the ocean from backing up by their continuous outflow. During times of low run-off, river currents may be overcome by tidal flow from the sea with the result that salty water may move many miles upstream.

(e) *Highway Use.* The use of salt on highways to melt winter ice and snow has been creating serious problems in rural areas of numerous countries. Salt from the highways has killed nearby trees and shrubberies of frontage homesteads. Worse still, the salt gets penetrated into the ground waters and polluted rural wells.

Large amounts of salinity in water cause problems other than those related to human consumption. Dissolved inorganic and mineral substances exert adverse effects on aquatic animal and plant life and cause many irrigation problems in the agricultural industry. Damage to aquatic life is primarily related to the osmosis process, assuming the dissolved substances are nontoxic. Generally, the concentration of dissolved materials in body fluids is the maximum that an aquatic organism can tolerate. When these organisms are in contact with water containing higher concentrations, there is a

tendency for water to move out of the cells of the organism into the surrounding water. The resulting increase in concentration within the cells of the organism can lead to death. Many fresh water species disappear when waters become brackish.

One of the most serious long-term effects of increased salinity of waters involves the use and re-use of water in irrigation. It has been estimated that about 25% of the irrigated land of the world is now affected to some degree by water salinity. Irrigation water brought onto a field always contains some dissolved salts. The concentration of these salts is in the range of 25—8000 mg/*l*. Plants extract water from the irrigated field, but most of the dissolved salts are excluded by the roots. Water that evaporates from the soil surface leaves dissolved salts behind. These two processes make residual salts to accumulate in the soil.

In order to preserve the salt balance of the soil and avoid damage to crops, the excess salt accumulation have to be leached from the soil with excess irrigation water. Hence, drainage water from the soil is having an increased concentration of salts which it carries back to the general water supply. Irrigation does not actually produce a pollutant in the form of dissolved salts but merely returns the salts to the general water supply in a more concentrated form.

In order to illustrate the serious nature of this problem, it is assumed that 20% of the total water flow in a river is withdrawn, used for irrigation, and returned at each of four successive projects along the river. The relative concentration of dissolved salts in the river would increase from an initial value of 1.00 to 1.25, 1.67, 2.50, and 5.00 following each usage.

Table 7.8 shows general crop responses to various concentrations of total dissolved inorganic solids (TDS) in irrigation water. In order to put these figures into perspective, it is worth mentioning that the Colorado River has a TDS of 750 mg/*l* by the time it reaches the Imperial Dam in California. Also, the recommended TDS level for drinking water has been less than 200 mg/*l*, and the permissible maximum has been 500 mg/*l*. A farmer who applies 5 feet of water

Table 7.8. Suggested Guidelines for Salinity in Irrigation Water

Crop response	*TDS mg/l*	*EC*[1] *mmhos/cm*
Water for which no detrimental effects will usually be noticed	<500	<0.75
Water which can have detrimental effects on sensitive crops	500-1,000	0.75-1.50
Water that may have adverse effects on many crops and requiring careful management practices	1,000-2,000	1.50-3.00
Water that can be used for salt-tolerant plants on permeable soils with careful management practices	2,000-5,000	3.00-7.50

[1]Electrical conductivity.

during the growing season in the Imperial Valley in California also applies 6 tons of dissolved salts per acre. All crops exhibit decreased growth and yield with increasing water salinity. The salinity is expressed in terms of electrical conductivity (EC) of a saturated extract of the soil. The EC values can be related to actual concentrations by use of Table 7.8.

In addition to total salt content, the nature of the individual salt components exerts effects on the soil. These components can be changed by previous use of the water. For example, water used in municipal and some industrial applications has been softened before use. The ions Ca^{2+} and Mg^{2+} are replaced by Na^+ resulting in water enriched with Na^+ ions. This high Na^+ concentration adversely affects soils and plants by breaking up soil aggregates and making the soil to become highly impermeable.

The toxic properties of numerous inorganic compounds, especially those of some of the heavier metallic elements, have been known for years. Some of these compounds are having desirable properties and so are routinely manufactured. Appropriate pre-

cautions are taken to insure the safety of individuals involved in the manufacturing process. The use of these compounds give rise to their introduction into the environment either directly or indirectly, intentionally or unintentionally. The recent detection of these metallic substances in air and water in concentrations approaching toxic levels has created a great amount of concern. The most toxic, persistent, and abundant of these compounds in the environment appear to be those of the metals mercury (Hg), lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), and nickel (Ni). *These metals accumulate in the bodies of organisms, remain for long periods of time, and behave as cumulative poisons.* More research is needed to determine the seriousness of these potential hazards.

7. Sediments

Sediments are soil and mineral particles which are washed from the land by storms and floodwaters, from croplands, unprotected forest soils, overgrazed pastures, strip mines, roads, and bullozed urban areas. Sediments are able to fill stream channels and reservoirs ; erode power turbines and pumping equipment ; reduce the amount of sunlight available to green aquatic plants ; plug water filters ; and blanket fish nests, spawn, and food supplies, thus reducing the fish and shellfish populations.

On a global scale it has been reported that the mass of material moved annually by rivers to the ocean was 9.3 billion metric tons before man's intervention and is now 24 billion metric tons, which would mean that the continents are now being lowered at the rate of 5.8 cm (2.3 in.) every 1000 years. (Man also moves small amounts of sediments from the sea to the land, as in dredging). The problem of the disappearance of the continents has been not as immediate as the problem of the loss of valuable topsoil from agriculturally productive land, of course.

Sediments are almost regarded as a type of pollution due to the naturally occurring process of erosion. Sediments produced by that process do represent the most extensive pollutants of surface waters. It is estimated that suspended solid loadings reaching natural waters

have been at least 700 times as large as the solid loadings from sewage discharge.

Two facts not commonly known are the effects man has had on erosion rates and the far-reaching effects of sedimentation. Erosion rates of land are increased 4-9 times by agricultural development and may be increased by a factor of 100 because of construction activities. Strip mining activities greatly influence the rate of erosion in an area. Sediment yields from stripmined areas average nearly 30,000 tons per square mile annually, an amount 10-60 times as great as yields from agricultural lands. The amount of sediment washed from an area has been found to depend very much upon the condition of the land. This is indicated by the data of Table 7.9. These data have been based on 2.4 inches of rain in 1 hour.

Table 7.9. Effect of Ground Cover on Erosion

	Good ground cover	*Fair ground cover*	*Poor ground cover*
% of ground covered with plants and litter	60-75	37	10
% of rain that runs off	2	14	73
Soil loss (tons/acre)	0.05	0.5	5 55

Sediment production is a tedious problem in some parts of the world. This variation is not all caused by man's activities, but also involves the type of soils, geology, topography, precipitation, and vegetation cover.

The detrimental effects of sediment in water are :

1. *Stream channels, harbors, and reservoirs are filled.* This makes channels to overflow more easily, changes flow rates and depths of channels, and reduces the useful life of reservoirs. Expensive dredging is needed to counteract these effects.

2. *Destroys aquatic animals.* Sediment settling on the bottom lowers fish and shelfish populations by blanketing fish nests and food supplies.

3. *Reduces light penetration into water.* The reduction in the amount of sunlight penetrating into the water lowers the rate of photosynthesis by plants, which in turn results in a decreased production of oxygen needed for normal stream balance.

4. *Water is clouded.* It increases the cost of treating water used for culinary purposes. Sediment passing through power plant turbines makes serious abrasion and wear. The hunting ability of fish get curtailed if they depend on their vision.

8. Radioactive Materials

Harmful radiation may result in water environments from the wastes of uranium and thorium mining and refining, from nuclear power plants ; and from industrial, medical, and scientific utilization of radioactive materials.

Many radioactive substances are lethal at relatively low concentrations and in minute amounts may be mutagenic.

Uranium and its decay products are elements which have highly unstable nuclei. The disintegration of these nuclei gives rise to radioactive emissions which may be highly injurious, even lethal, to living organisms. Four activities have been potential sources of radioactive pollutants, and each has been known to have been involved in environmental pollution.

1. The mining and processing of ores to produce usable radioactive substances.
2. The use of radioactive materials in nuclear weapons.
3. The use of radioactive materials in nuclear power plants.
4. The use of radioactive materials in medical, industrial, and research applications.

Typically, uranium ore is having about 2·5 lbs. of U_2O_3 per ton. Obviously, large amounts of ore could be processed to produce the material. The ore is crushed, finely ground, and leached with acid or alkali. The uranium could be recovered in a usable form from the leach liquors by various precipitation, solvent extraction, or ion exchange procedures. Radioactive wastes have been produced

in each of these operations. Perhaps the greatest problem of radioactive pollution, as a result of uranium production, has been caused by the large quantities of "uranium tailings" produced. This finely-divided solid material remains after useful materials have been leached out. Huge piles of these tailings are found in uranium producing areas. An estimated 12 million tons are piled up in the Colorado River Basin which is an active center of uranium production. As is the case with the strip-mine spoil bank, no one appears to be interested in the tailings once mining operations are halted.

These tailings create a radiation pollution problem as they contain radioactive decay products of uranium. Two of these radioactive materials are thorium-230 ($^{230}_{90}Th$) and radium-226 ($^{226}_{88}Ra$). Substances like these can be dissolved or eroded from piles of tailings by rainfall, and thus they can get mixed up into the general water supply. Radium and thorium is chemically similar to calcium and so get absorbed by the bones when taken into the body. Some waters in the Colorado River Basin have had the concentration of $^{226}_{88}Ra$ increase to about double the maximum level permissible for human consumption.

The grading of tailing piles and planting vegetation has been taken to reduce erosion and has been followed to some extent. However, this method does bring down the quantity of tailing radiation in surface waters.

An important source of radioisotopes is nuclear weapons testing. The amount and variety of radioactive materials formed depends on the type of weapon tested. Some of the radioisotopes have a very short half life and last only a few seconds or minutes, and some others may have a half-life of several hundred years. These materials reach the earth as radioactive fallout. Before the first test explosions were conducted, it was thought that fallout (dust and debris) would fall to earth quickly and at no great distance from the detonation site, thus the spread of radioactivity would be limited. However these assumptions have proved wrong, especially in the case

of large explosions. Radioactive particles can, remain suspended in the air long enough to circle the globe many times, dispersing as they go. It is true, however, that the main effects of atmospheric testing are found in the immediate vicinity of the detonation site. Because of concern about such fallout in 1963, of the Limited Nuclear Test Ban Treaty was signed. According to the U.S. and U.S.S.R. will limit testing of nuclear weapons to underground detonations.

The purpose of underground detonations, carried out in the U.S. at the Nevada test site, is to limit the amount of atmospheric fallout, and in majority of cases this is achieved. Occasionally accidental releases of radiation reach the atmosphere due to "venting" at the explosion site. When this happens, radioactive gases are forced up through the hole used to place the explosives. The leakage may take place through channels left for control and monitoring cables, natural cracks or fissures in the rock, fractures formed by the blast, or combinations of these. Sometimes venting occurs when the materials used to fill the hole are simply blown out. Leakage may immediately take place after the explosion or later, when rock and earth fall into the cavity formed by the explosion and leave a channel for gas venting.

In only 12 of 190 tests conducted at the Nevada site from 1961 through 1969 ventings were reported different amount of radiation are released. It is released near ground level and so poses no world-wide fallout problems, but it may result in very serious local hazards.

Atmospheric fallout, irrespective of the source, can have far-reaching effects and can be conveyed to man in a number of ways as shown in Fig. 7.1. The effects of radioisotopes on man can be illustrated. Strontium-90 ($^{90}_{38}Sr$), a component of radioactive fallout which has a half-life of 28 years, is chemically similar to calcium. Calcium is absorbed from the soil by plants and passed on to animals, where it is used in the formation of bones and teeth. Man gets calcium from both plant and animal sources like milk, vegetables, and cereal grains. Strontium is produced it from

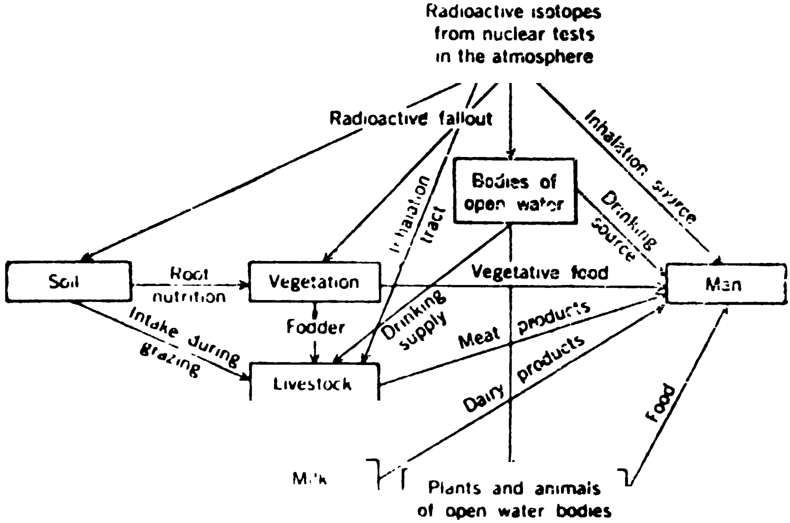


Fig 7.1. Transmission of radioactive fallout to man.

these sources and, due to chemical similarities to calcium it is also deposited in bones and teeth. The marrow of bones is the main site of blood-cell formation. The presence of radioactive strontium-90 in the surrounding bone tissue seriously curtails this which may result in production anemia or more serious disorders.

Cesium-137 ($^{137}_{55}Cs$) which is chemically similar to potassium is a common constituent of all living cells. Cesium from fallout passes to man through contaminated meat and dairy products or contaminated grains and leafy vegetables. Cesium contamination of foods results in the same effects as strontium contamination. The soft parts of the body, specially the muscles, are badly affected by the presence of cesium.

More and more of nuclear energy is being produced so as to meet the ever increasing demand for electrical power Nuclear generators are better as compared to more commonly used types. Because, nuclear energy is cheaper to use than that from conven-

tional sources such as fossil fuels or falling water. Moreover, nuclear generators do not produce any SO_2 or particulate pollutants commonly produced by fossil-fuel burning generators. By the year 2000, nuclear power is expected to be the main source of electric power generation.

Nuclear power plants are different from conventional electricity generating facilities. In the conventionally fueled power plant, fossil fuel is burnt to produce heat while in a nuclear plant the heat is generated by a nuclear reaction. In both the heat produces steam which turns a generator and produces electricity.

A typical nuclear reactor uses the fuel which is a mixture of uranium-235 ($^{235}_{92}U$) and uranium-238 ($^{238}_{92}U$). These isotopes are packed into stainless steel or zirconium tubes in the form of uranium oxide pellets. The total fuel load of a reactor core may consist of hundred tons or more of uranium oxide. The fuel-containing tubes are spaced in such a way as to sustain a controlled nuclear chain reaction of the uranium atoms. This reaction generates large amounts of heat energy. The temperature of this reacting core is maintained at about 1000°F with the help of circulating coolant.

Generally the coolant is water, which, is while circulating among the fuel elements, becomes heated to boiling. The steam formed is used to turn the turbine of an electrical generator. After passing through the turbine, this steam gets condensed and cooled by a secondary cooling system, generally made up of water from a nearby river or lake. The cooler water is then sent to the reactor core and the cycle begins again. This operation is shown in Fig. 7.2.

In same cases, a liquid metal (often sodium) is circulated through the reactor core, then to a heat exchanger where water is heated. The resulting steam drives a generator and the liquid metal recirculates. This type of arrangement adds the necessity of a heat exchange system between the reactor and generator turbine.

Four types of pollutants that are formed by nuclear generating plants are as under :

1. *Low level rodioactive liquid wastes.* Radioactive isotopes are produced when impurities in the primary coolant water and corrosion products from coolant pipes are bombarded with neutrons

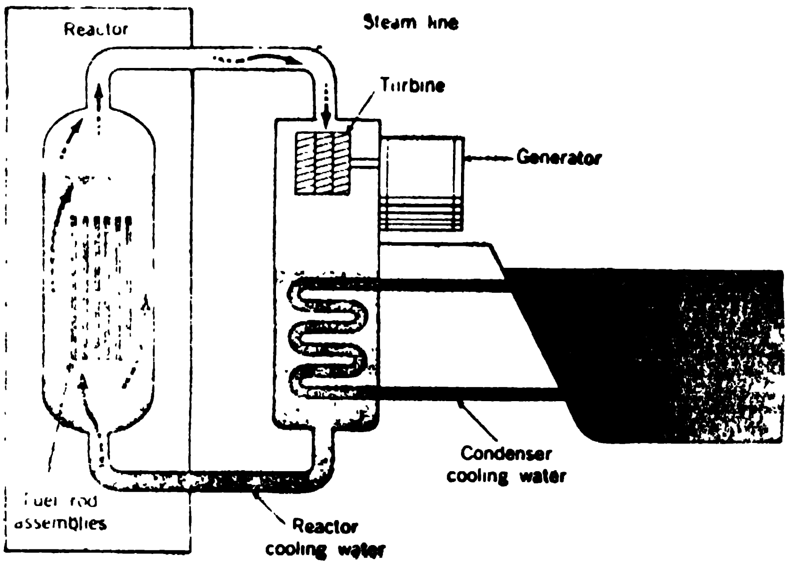


Fig. 7.2. The fuel elements in a nuclear reactor are usually cooled by a primary coolant in a closed system. To cool the primary coolant a secondary eoolant is necessary. It is the dumping of this secondary coolant into the environment that causes thermal loading problems.

from the core area. This can be avoided to some degree by using demineralized coolant water. This type of waste is now disposed of these days by sealing it in containers that are afterwards dropped into the ocean. There are unknowns in this disposal technique, such as the lifetime of the containers used, the waste within them, and the directions and speeds with which the containers or their contents move when subjected to underwater currents.

2. *Heat.* The secondary cooling system takes away huge amounts of heat from the reactors and mixes it into natural water supplies.

A variety of research laboratories, including medical and biochemical facilities, release radioactive wastes into the air and sewer systems. It is not now feasible to attempt to collect and dispose of these materials. Nor is it feasible to collect and bury the large amounts of radioisotope-containing liquids, solids, and gases forward by laboratory uses other than research, like diagnostics or treatment. Presently the amounts of radioactive waste discharged from such laboratory sources poses no threat to natural communities of plants, animals, and man.

3. *Liquid and gaseous wastes from fuel elements.* Complete sealing of the fuel in steel or zirconium containers is apparently impossible to attain or sustain. Minute cracks allow fission products to escape into the primary coolant. This further complicates the disposal problem of low level wastes discussed earlier.

4. *Fission products.* When in 1-3 years, fission products (the ashes of nuclear fuels) accumulate to the point that they absorb sufficient neutrons to slow or stop the chain reaction. Then the extremely radioactive fuel elements are removed and shipped in special containers to a fuel reprocessing plant. In these plants the fission products are separated from the remaining usable fuel. The fuel is returned to the reactor where it is used and the waste fission products are stored, in liquid form, in huge underground stainless steel tanks. Hundreds of millions of gallons of these high level wastes are now in storage.

9. Heat

Vast amounts of water find use for cooling purposes by steam-electric power plants (and other industries to a lesser extent). Cooling water is discharged at a raised temperature, and some rivers may have their temperatures so high (even up to 40°C) that fish life completely gets eliminated and the river becomes useless for assimilation or pollution further cooling.

Increasing the water temperature of a system is harmful since it generally alters the chemical, physical and biological characteristics of that system. In addition to the possibility of decreasing or eliminating various aquatic forms, it may also stimulate spawning at a time of year when food supplies are limited. This leads to starvation of the newly spawned individuals in the population. High temperatures also decrease the density and viscosity of water, causing an increased settling rate of suspended solids. Evaporation rate is increased and, in marine systems, this may lead to localized areas of abnormally high salinity.

Heat is not ordinarily thought of as a pollutant by many people, at least not in the same sense as a corrosive chemical. However, the addition of excess heat to a body of water brings about adverse effects as numerous as many of the chemical pollutants. This serious problem of thermal pollution originates primarily with the practice of using water as a coolant in many industrial processes. Most water used for this purpose gets returned, with the added heat, to the original sources. At present, about 70% of the water diverted to industrial use serves as a cooling medium.

Used coolant water frequently may be having a temperature 20°F higher than the river or stream to which it gets returned. This added heat raises the temperature of the natural waters, with the results that : (1) the amount of dissolved oxygen in the water gets decreased ; (2) the rates of chemical reactions have been increased ; (3) false temperature cues have been given to aquatic life ; and (4) lethal temperature limits may be exceeded.

The decreasing ability of water to contain dissolved oxygen as the temperature increases is shown graphically in Fig. 7.3.

The addition of heated water to a cooler, body of water may accelerate the lowering of DO levels due to density differences between the two. The less dense warm water tend to form a layer on top of the cooler, more dense water. This occurs particularly when the body of cool receiving water is deep. The resulting blanket of "hot" water cannot dissolve as much atmospheric oxygen

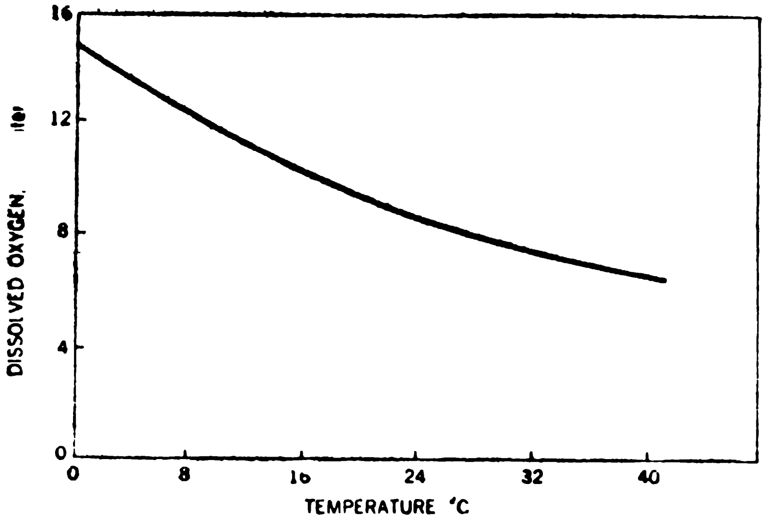


Fig. 7.3. The quantity of oxygen dissolved in water is related to temperature. The higher the temperature, the lower the oxygen content of the water. Thermal pollution can lower the oxygen content below the point necessary to sustain many animals.

as the underlying cold water, which is denied contact with the atmosphere. Normal biological reduction of the DO level of the atmospherically unreplenished lower layer may give rise to anaerobic conditions.

Another effect of this stratification may show up downstream from a dam when the oxygen deficient lower level get discharged through the lower gates of a dam. Serious effects on downstream fish life may result. Also, the ability of the stream below the dam to assimilate oxygen-demanding wastes will get curtailed.

The effects of heat in water have been sometimes seen in nature independent of man's interference. On hot summer days the temperature of shallow waters sometimes reaches a point which disallows a DO level sufficient to support some life. Under these conditions, suffocated fish are often occurred on the surface.

A rough rule of thumb often used by chemists has been that the rate of any chemical reaction, including those of respiration and oxidation, approximately doubles with every 10°C (18°F) increase in temperature. In thermally polluted water, fish need more oxygen due to an increased respiration rate. However, the available oxygen in such water gets decreased. Thus, thermal pollution affects fish in a double-barreled fashion.

Other reactions are also influenced. Trout eggs hatch in 165 days when incubated at 37°F. When water temperatures have been 54°F. only 32 days are needed and no hatching takes place at water temperatures in excess of 59°F. Such a result can be disastrous to fish populations. If the fish hatch early and find no natural food organisms available, they of course do not survive. The natural food of such hatchlings has been found to dependent on a food chain originating with plants whose abundance is a function of day length as well as temperature.

The life cycle and natural processes of many aquatic organisms have been closely and delicately geared to water temperature. Fish often migrate, spawn, and are otherwise distributed in response to water temperature cues. Shellfish, such as oysters, spawn within a few hours after their environment reaches a critical temperature. These normal life patterns of aquatic organisms can get completely disrupted by artificial changes in water temperatures.

Fish have been found to vary widely in their water temperature preferences. An indication of this has been the commonly used classification of fish as either cold- or warm-water species. An upper lethal, temperature limit exists for each species. It is known that temperatures well below the lethal value can bring about stress in organisms ; hence the much lower recommended values. Lethal limits can be exceeded, in some examples under conditions of warm water waste discharge.

Another factor to be considered in addition to the temperature change has been the rapidity with which the change occurs. Fish are able to acclimate themselves to moderate temperature changes

(below lethal levels) if the change has been not a sudden one. Normally a moderate temperature change over a 30-40 hour period could be handled by the fish. For instance, 95% of the eggs of largemouth bass perish when suddenly transferred from water at 65-70°F into water at 85°F. However, if similar eggs are kept in water and the temperature gradually increased to 85°F over a 30-40 hour time period, 80% of the eggs survive.

An additional threat to aquatic life has been created by the common practice of chlorinating coolant water prior to use. This is carried out to prevent bacterial growths that clog pipes. The chlorine affects organisms in the area receiving the used water until dilution occurs. The chlorine has been able to kill microorganisms important in some food chains and may in this way exert a negative influence on fish populations.

A problem of thermal population not related to aquatic life has been the reduced cooling capability of warmed waters. It is important because nuclear reactor power sources need about 50% more cooling water for a given temperature increase than similar power plants using fossil fuels, and it appears that nuclear plants will find use extensively in the future.

Different solutions to the thermal pollution problem have been postulated and some have been already in use. Several industries have incorporated cooling towers into their operations to remove heat from cooling water before returning it to the natural water supply. Two types of towers, wet and dry, have been used. Water is run over baffles in a thin layer in the wet tower. Cool air, entering at the bottom, circulates upward and removes heat from the water. In dry towers, air is forced over water-containing pipes by huge fans. Heat gets exchanged by radiation and convection from the pipes.

The use of cooling ponds or lakes has been another alternative. These ponds could act as ice-free wintering areas for waterfowl in northern locations or as a means of extending the range (northward) of certain fish. Both of these have been positive results of thermal pollution.

Although many schemes have been presented for using the waste heat in some commercially profitable way, no practical applications have been reported. Discharge water has been not hot enough to heat buildings, and the cost of transporting it to farms for irrigation purposes has been prohibitive even when improved crop production has been considered. A more promising idea involves the use of waste heat in desalination plants to aid evaporation processes. At present, this has been still only an idea. Indications have been that waste heat disposal will continue to be a problem for several years.

8

Sources of Contamination of Water Pollution

INTRODUCTION

The major sources of water contamination have been domestic, industrial and agricultural waste, as well as solid waste thermal pollution. Shipping water pollution and radioactive waste.

1. Domestic Water Pollution

It includes waste water from homes and commercial establishments. Domestic waste water arises from many small sources spread over a fairly wide area but is transmitted by sewers to a municipal waste treatment plant.

Generally, the impurities in domestic wastes get diluted and seldom total more than 0.1% of the total mass. This material has been largely organic and gets oxidized by bacterial decomposition to nitrate, phosphate, carbon dioxide, and water. As this type of decomposition needs the use of dissolved oxygen, it places an oxygen demand on the system. Because of this tendency to remove oxygen in the decomposition process, a common indicator used to monitor this type of input in receiving waters has been the *BOD* (*Biological Oxygen Demand*) *Test.* In this analysis the amount of oxygen for

decomposition is measured over a 5-day period. In systems receiving significant amounts of organic material, the bacterial decomposition will remove large amounts of dissolved oxygen, which causes oxygen depletion. These systems are considered to have a high BOD. Conversely, when the input of contaminants is absent or minimal, the oxygen levels will not be drastically reduced because the bacteria will not need an excessive amount of oxygen to decompose small amounts of materials. In these cases there would be a low BOD on the system.

Although approximately 70% of the population of the world is domiciled in buildings connected to sewage-treatment systems, the majority of these systems have been inadequate or inefficient and consist mainly of either primary or secondary treatment. These systems bring sewage to a central treatment facility and, after minimal treatment, release this material into waterways, lakes, oceans, or estuaries. This practice of concentrating sewage, subjecting it to minimal treatment, and then releasing the effluent leads to high phosphorus and nitrogen levels, as well as reduced oxygen concentrations in many of the receiving waters. The remaining 30% of the population have been residing in areas that are unsewered and either releases raw sewage into waterways or relies on cesspools or septic tanks for waste disposal. Sewage disposal by means of cesspools or septic tanks leads to serious localized problems. Release of raw sewage into waterways is able to intensity the problems which are associated primary or secondary treatment.

2. Industrial Water Pollution

This occurs in large amounts in specific locations, making collection and treatment fairly simple to accomplish. There are water-using factories which are discharging wastes with a total BOD load about three to four times as large as the load from the sewered population. Only about 7 or 8% of industrial waste waters have been disposed of in municipal sewer systems but, as mentioned above, they constitute about half the total municipal load.

As industrial pollution is found in large amounts in specific geographic areas, the collection and treatment of these materials should be easy to accomplish. Unfortunately, only a small percentage of the approximately 300,000 factories using and contaminating water in their manufacturing processes adequately treat the water prior to its release. As the specific type or types of industrial contamination vary with the geography and natural resources of a particular locality, no attempt has been made here to correlate water contaminants on a regional basis but merely to identify the possible sources of contamination.

Wastes from textile manufacturing processes could be generated from the washing out of the impurities in the fibers, as well as in the discarding of chemicals used in the processing of the fibers. Generally, these wastes have been organic, have a high BOD, and are extremely alkaline.

Food-processing wastes from meat, dairy, and sugar-beet processing, as well as brewing, distilling and canning operations, generate large amounts of organic by-products that have been disposed of in waste-water. When the wastewater is discarded, along with these by-products, it leads to high BODs and a consequent oxygen depletion in the receiving water via the same bacterial processes involved in the decomposition of domestic wastes.

The effluent released from pulp and paper processing operations has been a mixture of chemicals used in the digestion of raw wood chips, cellulose fibers, and dissolved lignin. This wastewater also has paper and wood preservatives, like pentachlorophenol and sodium pentachlorophenate, as well as methyl mercaptan, all of which have been toxic to fish. This effluent has been brownish in color and lowers the photosynthetic rate of aquatic communities by hindering sunlight penetration into the water column. Consequently, the organic wastes from these plants increase the BOD of the receiving water, while color imparted to the water interferes with sunlight penetration, reduces photosynthesis, and further lowers oxygen levels.

Metal industries keep a wide array of contaminants in their waste-water. The specific contaminants and concentrations depend solely on the particular manufacturing process employed. For example, steel mills employ and contaminate water in the coking of coal, the pickling of steel, and the washing of flue gases from blast furnaces. These waters, after use, tend to be acidic and have various deleterious substances, like phenol, cyanogen, ore, coke, and fine suspended solids. Other industries release traces of the metals produced or plated in their waste-water. Metals commonly found in these waste-waters have been chromium, mercury, nickel, lead, copper, and cadmium.

A variety of contaminants enter marine and freshwater environments in the effluents released from the various chemical manufacturing plants. The release of acids results not only from acid manufacturing processes but from practically all other chemical manufacturing processes as well. In addition, synthetic fibers (*e.g.*, rayons), bases, pesticides, and other organic and inorganic chemicals have been added, depending on the products being manufactured.

Most of the Indian rivers and fresh-water streams are seriously polluted by industrial wastes or effluents (Table 8.1) which come along waste-waters of different industries such as petro-chemical complexes ; fertilizer factories ; oil refineries ; pulp, paper, textile, sugar and steel mills, tanneries, distilleries, coal washeries, synthetic material plants for drugs, fibres, rubber, plastics, etc. The industrial wastes of these industries and mills include metals (copper, zinc, lead, mercury, etc.), detergents, petroleum, acids, alkalies, phenols, carbamates, alcohols, cyanide, arsenic, chlorine and many other inorganic and organic toxicants. All of these chemicals of industrial wastes have been toxic to animals and may bring about death or sublethal pathology of the liver, kidneys, reproductive systems, respiratory systems, or nervous systems in both in vertebrate and vertebrate aquatic animals (Wilbur, 1969). Chlorine which is added to water tc control growth of algae and bacteria in the cooling system of power station, may persist in streams to cause mortality of plankton and fish. Heavy fish mortality in river Sone near Dehri-

on-sone in Bihar is reported to cause by free chlorine content of the chemical wastes discharged by factories near Mirzapur in U.P.

Table 8.1. Some Indian rivers and their major sources of pollution

Name of the river	*Sources of Pollution*
1. Kali at Meerut (U.P.)	Sugar mills ; di leries ; paint, soap, rayon, silk, yarn, tin and glycerine industries.
2. Jamuna near Delhi	D.D.T. factory, sewage, Indraprastha Power Station, Delhi.
3. Ganga at Kanpur	Jute, chemical, metal and surgical industries ; tanneries, textile mills and great bulk of domestic sewage of highly organic nature.
4. Gomti near Lucknow (U.P)	Paper and pulp mills ; sewage.
5. Dajora in Bareilly (U.P.)	Synthetic rubber factories.
6. Damodar between Bokaro and Panchet	Fertilizers, fly ash from steel mills, suspended coal particles from washeries, and thermal power station.
7 Hoogly near Calcutta	Power stations ; paper pulp, jute, textiles, chemical mills, paint, varnishes, metal, steel, hydrogenated vegetable oils, rayon, and soap, match, shellac, and polythene industries and sewage.
8. Sone at Dalmianagar (Bihar)	Cement, pulp and paper mills.
9. Bhadra (Karnataka)	Pulp, paper and steel industries.
10. Cooum, Adyar and Buckinghum canal (Madras)	Domestic sewage, automobile workshops.
11. Cauvery (Tamil Nadu)	Sewage, tanneries, distilleries, paper and rayon mills.
12. Godavari	Paper mills.
13. Siwan (Bihar)	Paper, sulphur, cement, sugar mills.
14. Kulu (between Bombay and Kalyan)	Chemical factories, rayon mills and tanneries.
15. Suwao (in Balrampur)	Sugar industries.

Mercury like other heavy metals such as lead and cadmium has cropped up as a toxic agent of serious nature. Mercury, a by-product of the produetion of vinyl-chloride, is used in many chemical industries and it is also a by-product of some incinerators, power plants, laboratories and even hospitals, (**Aaronson**, 1971). In Japan, illness and even death occurred in the 1950s among fishermen who ingested fish, crabs, and shell-fish contaminated with methyl mercury from Japanese coastal industries This mercury poisoning produced a crippling and often fatal disease called **Minamata disease.** Initial symptoms of minamata disease included numbness of the limbs, lips, and tongue, impairment of motor control, deafness, and blurring of vision. Cellular degeneration occurred in the cerebellum, mid-brain, and cerebral cortex and this led to spasticity, figidity, stupor and coma. In Japan in 1953, due to Minamata disease 17 persons died and 23 were become permanently disabled.

In India, all the 14 major rivers have become polluted. The river Damodar is perhaps the most heavily polluted river. River Mini-Mahi in Baroda has been another heavily polluted river which is having a variety of industrial and petrochemical wastes. The river Cooum flowing through Madras has been got polluted by sewage so much that not even the zooplanktons have been able to thrive in it. One litre of Cooum water is having as much as 900 mg or iron, 275 mg of lead, 1313 mg of nickel and 32 mg of zinc. Besides heavy metals, very high levels of phosphates, slicates and nitrates also occur in the water. Sulphate levels ranging from 80-408 mg l^{-1} were the highest recorded among Indian rivers (The Times of India, May 27, 1987). The river Ganga from Hardwar to Calcutta is regarded as one unending sewer which is fit only to carry urban liquid waste, half burnt dead bodies, carrion, pesticides and insecticides. Nearly 312 industrial units are dumping their waste into the river, only a dozen have effluent treatment facilities. The 27 cities contribute 902 million litres of waste-water to the river each day. The water of Ganga affects the health of 250 million people of northern India.

Many of our lakes, notably the Dal lake, are becoming darkened, smelly and choked with excessive growth of algae.

3. Agricultural Water Pollution

It includes sediments, fertilizers, and farmanimal wastes. These pollutants can all enter waterways as runoff from agricultural lands but farm animal wastes are an especially large problem near the large feedlots on which thousands of animals are concentrated.

Agricultural waste includes the pesticides that are sprayed on crops, as well as sediment, fertilizers, and plant and animal debris that are carried into waterways during periods of rainfall or as runoff and during the irrigation of farmland. Wastes generated by farm animals are also included in this category. Until the mid-1950s animal wastes posed little problem, because they were, for the most part, reused as fertilizers. With the advent of agribusiness, however, the trend has been to ship the animals to large feedlots for fattening prior to marketing. This practice of keeping large numbers of animals in a small area has led to an excess of animal wastes generated in and confined to a given area, where it has been economically impossible to distribute wastes for reuse as fertilizers. These materials become a problem when they are allowed to enter waterways during the cleaning of the confinement areas or during periods of heavy rainfall, when runoff carries them into adjacent waterways. Since these wastes are organic, they increase the BOD of the receiving waters.

Inorganic fertilizers, being plant nutrients, lead to overfertilization of waterways when they enter these systems through runoff or during irrigation. The addition of excess plant nutrients can lead to a disturbance of the phosphorus/nitrogen balance in these systems as well as excessive plant growth. When the plants die, they settle to the bottom and, since they are organic, increase the BOD of the system during decomposition.

Soil erosion poses a fourfold problem. It increases the normal rate of filling of the waterways into which it washes, decreases the amount of fertile land for crop production, carries pesticide-coated soil particles into the water, and decreases the transparency of the water, which limits photosynthesis. In addition, the sediment carried

into fresh water systems tends to clog the gills of adult fish and settles out over incubating eggs, causing suffocation.

A remarkably large number of pesticides have come into widespread use in recent years. Many of these compounds have been not only non-biodegradable but are also only slightly soluble in water. Consequently, when sprayed on cropland they remain in the soil for long periods of time. During periods of heavy rainfall or when the crops are irrigated, they tend to be carried, as suspended particles, into surface, marine, or groundwater systems. In both fresh and marine systems they enter the food chain, undergo concentration in nontarget organisms, and increase in animal tissue to alarming levels. In surface, fresh, and groundwater systems they may also enter the drinking-water supplies of various communities.

4. **Solid Waste Pollution**

Solid waste varies in composition with the socioeconomic status of the generating community. The following materials could be classified as solid waste :

(*a*) Garbage, which includes all decomposable wastes from households, as well as from food, canning, freezing, and meat-processing operations that are not disposed of in wastewater.

(*b*) Rubbish includes all nondecomposable wastes. These materials may be either combustible or noncompustible. Combustible materials would include garden wastes, cloth, and paper. Non-combustible materials include masonry, some chemicals, metals, and glass.

(*c*) Sewage sludge is generated from the settling processes in primary, secondary, and tertiary treatment methods (see Chapter 9), as well as the solids from cesspools, which must be removed periodically.

(*d*) Miscellaneous materials include industrial wastes, such as chemicals, paint, and explosives, as well as mining wastes, such as slag heaps and mine tailings.

The disposal of solid waste poses many problems, depending upon both the type of waste and the disposal method employed. The majority of the waste classified as combustible—rubbish, garbage, and sewage sludge—has been disposed of by one of three major methods : incineration, using it as landfill, or disposal by ocean dumping. Incineration generally gives to air pollution ; landfill operations or ocean dumping lead to water contamination. If landfill disposal is used, the material, as it decomposes, will dissolve in or become suspended in the rainwater percolating into the ground and thus into subsurface aquifers. This tends to contaminate not only groundwater but also surface waters, since the two systems are ultimately interconnected. Because of the highly organic nature of this material, a large BOD is placed on the receiving waters, and the sediment becomes coated with a highly organic ooze. Non-combustible materials have been generally disposed of in landfill sites or by ocean dumping.

5. Thermal Pollution

Thermal pollution takes place because many electric-generating companies use water in the process of cooling their generators. This heated water is then released into the system from which it was drawn, causing a warming trend of the surface waters. Thermal pollution results when the heated effluent is released into poorly flushed systems. In these cases permanent temperature increases often result, which tend to decrease the solubility of dissolved oxygen. In lakes it also becomes possible to bring about nutrient redistributions and prolong summer stagnation periods.

When heated water gets released into large, well-flushed marine systems there is little if any permanent temperature rise. There are, however, problems related to the operation of plants utilizing marine waters in the cooling process. Evidence reveals that seawater tends to corrode the cooling pipes, which are generally constructed of a copper nickel alloy termed Monel. These metals readily dissolve in the heated seawater and are then released into the marine environment together with the heated effluent. This adds to the nicked and

copper concentrations of these systems. In addition, the screens covering the water-intake pipes rapidly foul with marine organisms, which decreases the flow of water into the plant. The screens have been commonly cleaned by using a concentrated detergent solution or copper sulfate. These cleaning materials have been then released into and contaminated the surrounding waters.

6. Shipping Water Pollution

It includes both human sewage and other wastes, the most important of which has been oil. There are about 15 million watercrafts on navigable waters and their combined waste discharges are equivalent to a city with a population of 2,000,000. Oil pollution, an oxygen-demanding waste, is of concern not only from sensational major spills from ships and offshore drilling rigs but also from small spills and cleaning operations.

Oil pollution results from accidents involving oil tankers and from spills at offshore oil drilling sites. A more persistent source of oil pollution results from the practice of oil tankers, after they deliver the oil, to fill the empty tanks with seawater to act as ballast for the return trip. Prior to docking, the seawater ballast, contaminated with the oil that remains in the tanks, is discharged. Although this practice is illegal, it is difficult to prevent. The alternative is to pump the contaminated seawater into tanks at port. This is not only inconvenient but uneconomical. In addition, there will remain the problem of disposal when the disposal tanks are full.

7. Radioactive Waste Pollution

The major sources of radioactive wastes have been nuclear explosives, accidents at nuclear power plants, fuel-reprocessing plants, and research laboratories and hospitals that release these wastes into the atmosphere or into wastewater. Presently, most interest centers on radioactive iodine and strontium, since man is at the end of the food chains that concentrate these elements. Much more research has been necessary before the implications of long-term exposure to low-level radiation can be found out.

The significance of the various parameters discussed and their use as water-quality indicators has been summarized in Table 8.2.

TABLE 8.2 Water-quality Indicators

Parameter	*Significance*	*Level*
Dissolved oxygen	General indicator of water quality; source of O_2 for respiration	Minimum acceptable level, ..5 mg/liter; 10-15 mg/liter for reproduction of desirable fish
Total suspended solids	Clog fish gills, bury eggs, reduce light penetration, increase heat absorption	Dependent on location
Total dissolved solids	Represents total mineral content which may or may not be toxic	A maximum of 400 mg/liter for diverse fish populations
BOD	Amount of dissolved oxygen removed during decomposition of organic matter in a given time; a general indicator of contamination due to biodegradable organics	*BOD* *Water Status* 1 mg/liter Very clean 2 mg/liter Clean 3 mg/liter Fairly clean 5 mg/liter Doubtful 10 mg/liter Contaminated
COD	Indicates the concentration of materials oxidizable .. chemical reaction	0-5 mg/liter indicates very clean streams
pH	Indicates the addition of acids or bases	pH depends on actual system
Irom	Excessive amounts can clog fish gills; indicates drainage from iron-bearing sediments, mines, industrial processes	A maximum of 0.7 mg/liter for diverse fish populations
Manganese	Concentration low in natural systems due to low solubility; high concentrations indicates contamination	A maximum of 1 mg/liter is a common criterion for stream quality

Parameter	*Significance*	*Level*
Copper	Indicates drainage from copper-bearing sediment, mines, plating, or other industrial sources	A maximum of 0.02-10 mg/liter is a common criterion for stream quality
Zinc	Indicates mine drainage or industrial input	A maximum of 1 mg/liter is a common criterion for stream quality
Hg, Cd, Pb, Ni, Cr, Ag, etc.	Indicates industrial input	A maximum of 1 mg/liter is a common criterion for stream quality
Nitrate	A major plant nutrient; in high-concentrations it can promote excessive plant growth; major sources are fertilizers, sludge, and sewage	A maximum of 0.3 mg/liter to prevent excessive fertilization of streams
Phosphate	A major plant nutrient; major sources are detergents, fertilizer, sewage	A maximum of 0.03-0 40 mg/liter total inorganic phosphate is a common criterion

9

General Adverse Effects of Water Pollutants

INTRODUCTION

A pollutant is regarded to be an undesirable or deleterious modification of the environment. The modification may actually or potentially influence human life, living conditions, cultural assets, or the life cycles of the indigenous plant and/or animal communities that inhabit a given system. The major sources of pollution, are regarded to be domestic, industrial, agricultural, radioactive, and solid wastes, as well as thermal pollution and oil spills. These contaminants could be conveniently subdivided into four categories on the basis of their effects on a given system regardless of their source : (1) substances that lead to oxygen depletion, (2) excess plant nutrients, (3) agents of biological dysfunction, and (4) sedimentary and erosional processes.

A given contaminant may be included into one or more of these categories depending on many factors, like its mode of action, the amount of dilution it encounters as it travels from the point of input, the flushing rate of the system into which the contaminant is released, and the tolerances of the organisms encountered. Each contaminant must, therefore, be evaluated in terms of the particular characteristics of the receiving water. For instance, the consequences

of releasing a small amount of raw sewage into a shallow, artificial pond would be totally different from the release of this material into the deep ocean. The differences have been one of degree and are due not to the inherent differences between marine and fresh water but rather to the differences in volume, circulation patterns, and degree of dilution Hence a shallow, poorly flushed pond could be expected to behave in a fashion similar to a shallow, poorly flushed estuary when a contaminant has been introduced.

Not only each contaminant must be evaluated in terms of the particular characteristics of the receiving water, but the effects of synergism must also be regarded. Synergism may be defined as a combination of factors (in this case, contaminants) that reinforce the activities or effects of each other. Synergistic effects tend to increase the impact of a contaminant, because the total effect from the interaction of these contaminants with other materials that could be present within the environment, or within a specific organism, has been generally greater than the effects of each individual contaminant. Thus it has been generally impossible to evaluate the effects of individual contaminants on a given system since, in many cases, the combined effects of two or more contaminants have been more severe than identical concentrations of a single contaminant. For example, cyanides in water, while toxic to aquatic life, have been extremely lethal in the presence of cadmium and/or zinc. Thus the presence of cadmium and zinc has been said to have a synergistic effect on the toxicity of cyanides.

Marine and surface freshwater systems are generally affected similarly by the addition of deleterious materials. Groundwater systems have been subjected to completely different ecological factors (total absence of a euphotic zone, for example), have been affected in a different manner by the input of various contaminants, and will be considered separately.

REDUCTION IN OXYGEN LEVELS

Factors as diverse as oil spills, heat, suspended sediment, organic wastes, and some inorganic wastes have been found to

decrease the available oxygen in a given system. Although the end result, oxygen depletion, has been the same, the mechanisms leading to oxygen depletion vary. There have been four major methods that may are able to reduce the oxygen levels within a given system : (1) decreasing the photosynthetic rate of the plants, (2) decreasing the solubility of the oxygen within the water column, (3) interfering with the diffusion of atmospheric oxygen at the air-water interface, and (4) increasing the oxygen consumption of the aerobic bacterial component of the system (increasing the BOD).

1. Decreased Photosynthetic Rate

Photosynthetic rate can be changed by increasing the turbidity of the water column, thereby decreasing the amount of light that enters a given water column. This may take place from suspended particles that enter a given system either by erosion during periods of rainfall or during the irrigation of crops. This material enters the water, physically blocks the amount of light entering the system, and thereby lowers the amount of light available for photosynthesis. As all plants need sunlight to provide the energy necessary to carry on photosynthesis, excessive addition of sediment will be able to reduce oxygen levels within the water column and, if prolonged, may be able to eliminate the plant life altogether. This would have the added effect of eliminating the food source of the primary consumers. The subsequent death and decomposition of these organisms would increase the decomposition rate in the regeneration zone and further increase the BOD on the system. Light could also be physically blocked from the water column by the input of highly colored effluent from dyeing processes in the textile industry and from paper-mill effluents. The textile industry has been releasing a variety of highly colored effluents, while paper-mill effluents tend to be a deep brown in color. Many of these highly colored effluents have been found to decrease light penetration through the water column, and thereby interfere with aquatic productivity in both freshwater and marine environments.

It is also possible to reduce photosynthetic rates by directly eliminating the plants that produce the oxygen. Mercury, which

enters the environment from a variety of sources (discarded electrical batteries, mercury-based pesticides, mining operations, etc.), travels to the regeneration zone, where, by bacterial action, it gets converted to the organic methyl mercury, which is soluble in water. After it has been in its soluble form, it has been capable of entering the food chain through uptake by phytoplankton or by direct assimilation by filter feeders. Mercury has been highly toxic to phytoplankton. It has been found that photosynthesis gets inhibited at mercury concentrations of 0.1 parts per billion (ppb). Many pesticides (in addition to those containing mercury) are also known to kill phytoplankton, thus reducing photosynthetic rates, and hence oxygen levels, in the systems they enter.

2. Decreased Oxygen Solubility

Oxygen levels have been also decreased as the temperature of a given system is increased. Increasing temperatures tends to increase the molecular motion of the water and any dissolved gases, which decrease the solubility of the dissolved oxygen. Lakes have been especially sensitive to increased water temperatures, since this reinforces the temperature—density barrier and prevents efficient mixing of the surface euphotic zone and the hypolimnion. Thus, if the temperature input has been great enough to prevent or delay the normal fall overturn, severe and prolonged anaerobic conditions will take place in the hypolimnion. This will causes overkills of hypolimnetic populations. In addition, higher temperatures have been favorable to increased bacterial growth and also increase the metabolic processes of the bacteria. This has the net effect of increasing the decomposition rate in the regeneration zone. As bacterial decomposition (aerobic) needs oxygen, an increase in the rate will also tend to increase the depletion of oxygen levels.

3. Decreased Diffusion of Oxygen

Substances that interfere with the diffusion of oxygen at the air-water interface by blanketing the water surface and physically preventing oxygen from entering the system are also able to reduce

the amount of available oxygen. Oil entering the environment from a variety of sources decreases oxygen levels in this manner. For example, the *Torrey Canyon* disaster of 1967 released 117,000 tons of crude oil. This oil blanketed large areas of the marine waters and, in addition to reducing oxygen diffusion, destroyed entire seabird colonies, harmed other marine organisms, and eventually coated both British and French beaches, temporarily ending their use as recreational facilities. A less-well-known source of oil pollution is the disposal of used motor oil. It is estimated that 350 million gallons of used motor oil get generated per year. As it is economically unfeasible to re-refine this oil, it is treated as a waste product and is eventually poured into municipal sewage systems, into storm drains, or directly into a convenient water-way. Ultimately the material released into sewage systems or into storm drains finds its way into streams, lakes, or estuarine waters, where it behaves similarly but on a reduced scale to the oil spilled by the *Torrey Canyon*.

The leaves of deciduous hardwoods, falling into streams in the autumn, can be able to reduce oxygen levels by hindering sunlight penetration as they float on the water's surface, and can interfere with the exchange of oxygen at the air-water interface. In addition, the leaves eventually sink, reach the regeneration zone, and decompose, thereby increasing the BOD on the system. These effects become important when they take place during periods of reduced stream flow (generally in the autumn of a dry summer). At these times a combination of reduced oxygen levels and low water volume will be responsible for lowered oxygen concentrations in localized areas. These effects have been transitory, however, and seldom so long prolonged as to completely reduce oxygen levels over a long period of time. In addition, all these materials have been biodegradable and do not bring about prolonged, unaesthetic results.

4. Increased Oxygen Demand

The oxygen demand (BOD) of a system can be increased by the addition of both organic and some inorganic substance to the environment. In general, organic contaminants entering systems

from municipal sewage-treatment plants or as raw sewage as well as animal wastes from feedlot cleaning operations and plant and animal residues from food processing operations, are the major source of organic wastes entering water-ways. All of this organic material eventually reaches the regeneration zone, where it can be broken into its component parts through bacterial action. Initially this is accomplished by aerobic bacteria, which require oxygen to perform the decomposition process. As there is a large amount of organic matter to be broken down, the bacteria remove large quantities of dissolved oxygen from the system (the BOD increases). As additional material has been added to the regeneration zone, more oxygen is removed, thus decreasing the oxygen levels further and accelerating the problem. If the input of material continues for protracted periods (as it does in the vicinity of industrial or municipal outfalls) the oxygen levels will decrease drastically and the system will become permanently anaerobic in these areas.

In most natural systems anaerobic conditions have been reaching a peak a short distance downstream from the point of input. This point coincides with the disappearance of the normal plant and animal communities and the appearance of large populations of undesirable or unaesthetic organisms that are able to prosper under these largely anaerobic conditions. Typical organisms occurred in these areas have been species of gas-producing bacteria that reduce sulfate (from paper-processing operations), the increasingly common white sewage fungus (actually a species of bacteria—*Sphaerotilus natans*), the protozoan that preys on bacteria—*Paramecium putrinum*, and the small thread-like sewage worm *Tubifex tubifex*. In areas subjected to such strenuous environmental conditions the species diversity has been low, but the populations of the few adaptable species are large. Unfortunately, these organisms have been undesirable and/or unaesthetic and can rarely be utilized as food. Fish populations have been either totally eliminated if the anaerobic conditions are widespread, or will tend to migrate to uncontaminated regions. In either event these organisms have been absent in the areas of immediate contamination.

Inorganic materials like iron (ferrous) salts from mining drainage operations and sulfides from pulp and paper processing plants have been able to decrease the oxygen levels in fresh and marine environments. These inorganics decrease oxygen levels by using the dissolved oxygen in processes that serve to convert these materials into different inorganic chemical forms. Generally, the addition of inorganics has been said to place a *chemical oxygen demand* (*COD*) on the system.

In most of our rivers today the water has been just barely acceptable before it is utilized by a downstream community, being pretreated prior to distribution to this community, and then is re-contaminated and treated prior to release back into the river. The rivers seldom are having an opportunity to naturally and totally purify themselves before the water is reused, recontaminated, and re-released farther down-stream. Thus the river system has been generally low in oxygen, and undesirable and/or unaesthetic organisms are generally found throughout its entire course. Lakes are even more susceptible to contamination, because they are poorly flushed and any materials that are added will tend to accumulate and eventually build up to hign concentrations.

EXCESSIVE PLANT NUTRIENTS

The addition of plant nutrients (phosphorus and nitrogen) to marine and surface freshwater systems will having a number of deleterious effects. In addition, it is to be noted that the organic materials discussed above will decompose into their constituent forms. A portion of their products of decomposition have been the plant nutrients : inorganic phosphate and inorganic nitrate. In addition to their effects on oxygen levels, these materials will also add to the problems caused by excessive fertilization discussed in this section. These effects are commonly termed *eutrophication.* For details see Eutrophication.

It is to be noted that in surface freshwater systems phosphate has been commonly the limiting factor, while in marine systems

nitrate tends to limit plant growth and, thus, overall productivity. Consequently, the material that is likely to lead to excessive overfertilization has been the substance that has been commonly limiting in undisturbed systems. In other words, the addition of phosphate to many freshwater systems would lead to excessive plant growth, since, in normal freshwater systems, phosphorus is generally limiting. In marine systems the reverse would generally be true. As nitrogen is limiting, the addition of contaminants containing nitrogen would be able to remove the limiting factor and excessive plant growth would occur.

Overfertilization of a system has been harmful since it destroys the integrity of the community by rapidly altering nutrient relationships and plant-animal interrelationships that have slowly evolved over the centuries. The end result has been generally the elimination of many or all of the normal populations, which are replaced by a few, opportunistic forms that are more tolerant of the rapidly changing conditions. Regardless of the system, overfertilization tends to remove the limiting factors and allow for the proliferation of and abnormally high growth and reproductive rates of plant populations. If the plants normally found in the disturbed system multiply rapidly, the consumer organisms cannot keep pace with this rapid increase. Therefore, more and more plants will remain uneaten by the consumers. These plants will ultimately die and add excessive material to the regeneration zone to be decomposed. If the source of overfertilization continues unabated, there will occur an excessive increase in the materials entering the regeneration zone. This will ultimately place an excessive demand on the dissolved oxygen of the system, and oxygen levels will decline. Many fish have been extremely sensitive to reduced oxygen levels, and they will tend to be eliminated. In addition, the accelerated rate of settleable organic matter will be able to increase the rate at which the bottom sediments have been covered with highly organic silts and muds. This material will tend to cover and smother many benthic forms adapted to living on sandy substrates, in addition to suffocating eggs and larval forms of many of the normal animals. In some cases

excessive fertilization tends to foster the growth of new plant species that did not take place in the area previous to this type of disruption. These new forms often tend to outcompete the indigenous forms in these altered conditions and eventually eliminate them. In many cases the primary consumers have been unable to utilize these new forms as a food source and are therefore eliminated from the system, bringing about grave consequences to the entire food chain.

It has been to be recalled that all systems tend to age naturally. This normal aging has been accompanied by a gradual increase in the nutrient levels, the slow conversion of the benthic sediments to a mud bottom, and a normal, orderly succession of the plant and animal communities. Overfertilization tends to "mimic" the normal aging process. The problem, however, has been that in these cases conditions have been altered rapidly. This prevents an orderly succession in which the community structure is able to slowly change and/or evolve in response to the normally slow changes. In community change, associated with contamination, conditions change so rapidly that entire plant and animal communities get eliminated, permitting undesirable opportunistic forms to occupy their place.

Excessive fertilization has been the consequence of the release of improperly treated sewage into waterways as well as animal wastes from feedlot cleaning operations and animal and plant residues released as a by-product of food-processing operations. Perhaps the greatest source of excess plant nutrients in waterways has been the use of inorganic fertilizers on agricultural lands as well as on lawns and backyard vegetable gardens. The problem associated with the use of inorganic fertilizers involves their effects on the soil on which they are spread. In natural soils much of the nitrogen has been contained in the highly organic humus. Generally, inorganic nitrogen accounts for 2% or less of the total nitrogen content of such soils ; the remainder has been combined in the large organic molecules of the humus (derived from plant residues, animal manure, etc.). A high humic level provides a favorable medium for the chemical reactions and mineral transport necessary for the growth of food

crops. The soil bacteria slowly decompose the humus to form the nitrates and other nutrients needed by the plants for optimal growth. In addition, the humus tends to increase the ability of the soil to retain water, thereby decreasing the necessity for excessive irrigation and the erosion problems associated with rainfall. It has to be noted that irrigation practices decrease the amount of available water in a given system, while erosion causes loss of soil from agricultural areas. The eroded soil also enters waterways and decreases the amount of available light for photosynthesis, causing siltation problems.

Humus declines in lands heavily fertilized with inorganic fertilizers. This has been due to the failure to return crop and animal residues to the fields from which they were removed by harvesting. These materials, if returned to the fields, would aid in maintaining humus levels. Consequently, as humus levels decline, the nitrogen, with no organic humus to "bind" it to the soil, will tend to leach out as the soil has been irrigated. This lowers the soil fertility and necessitates additional applications of fertilizer. Attempts to raise soil fertility by additional fertilization (with no addition of humus) will make a further decline in humus levels, which will cause the soil to retain less nitrogen and lead to further applications of inorganic fertilizers. It has to be noted that the inorganic fertilizers themselves have been not nutrient-deficient, since it had been demonstrated that if plant and animal residues (humus) are supplied along with the inorganic fertilizers, the humic levels of the soil will increase (thus improving the soil quality). Consequently, the materials discarded by the food-processing industry (plant residues) and by the practice of maintaining large numbers of animals on feedlots (manure generation) have been the materials that would improve soil quality. Presently, these materials treated as waste, discarded, enter waterways, and lead or contribute to their degradation.

The use of inorganic fertilizer has increased twentyfold in the past 25 years. This causes a decline in soil quality in much of the nation's farmland. As humus levels decline and the soil's ability to

retain nitrate is decreased, additional application of fertilizer is required to achieve the desired growth rate. This fertilizer tends to rapidly leach from the soil and enter waterways. These practices have been primarily responsible for the alarming rise in the nitrogen levels in the nation's waterways.

AGENTS OF BIOLOGICAL DYSFUNCTION

The *agents of biological dysfunction* will refer to any contaminant that either directly kills organisms or that interferes with their metabolic or physiological activity or their genetic or reproductive capabilities in such a manner as to threaten the success of a natural population in a given system. In addition, any material that appears to be harmless or to have a negligible effect when ingested, assimilated, and so on by members of one population but tends to accumulate in the tissues of these or of other organisms as it "passes up" the food chain to ultimately affect the success of higher consumers would also fall into this category.

The major materials in this category include the various persistent pesticides, heavy metals (primarily mercury, cadmium, lead, and copper), the by-products of the plastics industry (PVCs and PCBs), heat, and radioactive wastes. By strict definition, many of the materials previously discussed could be considered to fall into this category, since they, too, have deleterious effects on natural populations. However, in this section, only those materials directly related to metabolic, physiological, genetic, or reproductive interferences will be taken into consideration.

Perhaps the most alarming and well-documented effect of many of these substances has been their tendency to increase to significant concentrations in the various organisms as they pass up the food chain. This phenomenon is called *biological magnification*, and is known to be responsible for such diverse occurrences as eggshell thinning in the osprey, gross birth defects in terns, and unacceptably high DDT levels in the milk of human mothers.

DDT is a chlorinated hydrocarbon which provides the classic example of biological magnification. Although it has been only slightly soluble in water, it has been extremely soluble in organic fatty tissues. Algae, in the process of assimilating dissolved materials from the water, indiscriminantly take in and accumulate DDT. The DDT concentrates in their cellular fat bodies and increases on the order of parts per million. Primary consumers (zooplankton, shellfish, etc.), each feeding on tens or hundreds of thousands of algae during their life cycles, will be able to accumulate DDT in the tens of parts per million. The secondary consumers (small fish) that feed on the zooplankton will further concentrate this material and when they, in turn, are preyed upon by the larger fish, these tertiary consumers (since they are feeding on thousands of smaller fish) will concentrate the DDT to significant levels prior to passing it on to the top consumers. Hence, this material tends to concentrate in animal tissues at each succeeding step in the food chain, and its effects, if not immediately lethal to the lower consumers, are generally evident in the higher consumers only after many months or years of concentration.

Chlorinated Hydrocarbons

The other chlorinated hydrocarbons (aldrin, dieldrin, benzene hexachloride, etc.) have been believed to follow similar environmental pathways. Recently, another class of chlorinated hydrocarbons, the polychlorinated biphenyls (PCBs) have been known to exert serious environmental effects. This material finds use extensively as heat-exchange and insulating fluids in high-voltage electrical equipment. In addition, it has been added as stabilizers to paints, plastics, and rubber to make these materials resistant to decomposition processes. The toxicity of this material varies with the species of fish. For example, it is toxic to bluegills and catfish in concentrations above 20 ppm ; lethal levels for trout are 8 ppb and for shrimp as low as 1 ppb. In the osprey (top consumers feeding on fish), concentrations of 1000 ppm are found.

Recent studies indicate that PCBs are responsible for gross birth defects that are appearing with increasing frequency in the tern

colony. Workers from the American Museum of Natural History have noted newly hatched chicks with four legs, others with undeveloped legs and feet, or with rudimentary and displaced upper mandibles (bills). Another chick was noted that had no left eye and a crossed bill. This evidence indicates that while the PCBs follows the same pathway of biological magnification exhibited by the other chlorinated hydrocarbons, the end result is different in terns.

Metals

Metals commonly find their way into waterways after they have been disposed of in various industrial processes. The effects of many of these metals (copper, lead, and mercury) have been well known. The effects of other metals (such as chromium, cadmium, cobalt and nickel) the environmental pathways that they may take, and their effects on aquatic and human populations could be less well known. However, the fact that they are found in human food supplies or in the food source of these organisms, is a strong argument for halting further addition of these materials to waterways until their effects have been determined.

Lead and mercury have been two of the most widely studied metals. Man in an important factor in increasing the mercury levels of the various waterways. Since these streams ultimately enter into the coastal environment, it is to be expected that this material will eventually enter these systems in ever-increasing amounts.

Metallic mercury has been relatively nontoxic to organisms; however, once it is in its organic form (methyl mercury), its toxicity increases markedly. Since the bacterial conversion of mercury to methyl mercury is continuous, the metallic mercury added to the various systems will act as a methyl mercury reservoir that will continue to yield the more toxic form even should the addition of mercury be halted. Methyl mercury has been known to get concentrated by other organisms and to undergo biological magnification in the food chain. Fish, for example, tend to both absorb it directly

through their gills and also get additional mercury incorporated in their food. As methyl mercury has been more easily absorbed and more slowly excreted than the inorganic mercury, it magnifies to extremely large concentrations in fish tissue. In addition to decreasing the vitality of these aquatic populations, mercury, when ingested by man, can give rise to blindness, deafness, insanity, and/or death.

Lead is a remarkably well-distributed element. It is even found in the polar ice caps. Analysis of lead concentrations in the annual ice layers deposited on the Greenland and Antarctic ice caps showed an increase in lead concentrations from less than 0.001 microgram per kilogram ($\mu g/kg$) deposited at the 800 B.C. level, to 0.03 $\mu g/kg$ deposited at the 1815 level. These concentrations got soared to over 0.20 $\mu g/kg$ in the present layer.

Presently, the sources of lead contamination vary from industrial input to the solder used to seal food cans. Evidence reveals that most of the lead enters aquatic systems as particulate lead washed from the atmosphere during rainfall. Numerous studies show that lead gets absorbed by phytoplankton or filter feeders and then concentrates as it enters and passes up the food chain.

Copper enters from a variety of sources and may be taken up by the phytoplankton and passed up the food chain. Eventually, copper levels reach sufficient concentrations to impart color, to impair metabolic processes, or to kill various organisms (copper has been known to be toxic to lobsters in concentrations as low as 1 μg/litre).

Other metals, like cadmium, cobalt, and nickel, are also increasing in estuaries. Both clams and oysters are utilized as a human food source. As there have been cases of human illness associated with the excessive intake of these materials and as these have been capable of increasing to high levels in human food sources, further additions of these materials to waterways must be halted.

Heat

The solubility of oxygen decreases as water temperatures increase. In addition, the respiration rates of all organisms (including the bacteria) double with each 10°C rise in temperature, which places an added BOD on the affected system. Temperature effects also tend to be synergistic. For example, carp at 1°C have been able to tolerate CO_2 levels of 120 ppm, while at 36°C, CO_2 concentrations of 55 to 60 ppm might prove to be lethal. In other words, the tolerance of carp to CO_2 gets decreased as temperature increases. Similar effects are known to occur with other toxic materials.

Temperature also affects reproductive behaviour in many aquatic and marine organisms. Many organisms have been induced to spawn prematurely in response to increased water temperatures. Consequently, when water temperatures get raised, the normal spawning sequence gets disrupted. In many instances when organisms get induced to spawn at abnormal times (too early in the season, for example) due to the artificial raising of the temperature of a given system, the normal food supply needed by the young may not yet be available. This could give rise to the elimination of the young individuals in a given area.

Radioactive Wastes

Radioactive wastes have been reported to be directly lethal to organisms or they may give rise to genetic disruption. Evidence also reveals that some radioactive materials (*e.g.*, strontium) may be magnified as they pass up the food chain. Elaborate safety precautions have, thus far, prevented significant concentrations of radioactive materials from entering the environment. The projected increases in the use of this material in the future will give rise to additional problems for the safe transportation, storage, and disposal of this material.

SEDIMENTS AND EROSION

Sediments are having a variety of deleterious effects on waterways : they enter waterways and interfere with photosynthesis by

hindering light penetration through the water column. Sediments also clog the gills of fish and settle out and blanket the normal bottom sediments, eliminate spawning areas, and smother the eggs of many species of marine and freshwater organisms. In agricultural areas they tend to get coated with the various pesticides that have been applied to crops. When these sediments get carried into waterways by erosional and/or irrigational process, they also carry in the pesticides and add to the pesticide levels of these systems. In addition, sediments ultimately settle out in waterways, behind dams, and so on, and interfere with navigation and/or water storage, necessitating the frequent dredging of these areas. Two other effects involving sediments and related to unwise management practices have been coastal erosion control and salt-marsh landfill operations.

Coastal Erosion

The interference with coastal longshore transportation although not a consequence of pollution, has been a consequence of unwise management practices. The longshore current is formed by wind striking a shoreline on an angle and setting water in motion in the same general direction as the wind.

At any given time a storm may be able to strike the coastline and focus its major force at one particular point. As the waves will strike the beach at this point with increased force and frequency, the beach will be temporarily cut back at this point. After the storm passes, however, the normal sediment flow will get reestablished and the beach will rebuild.

Problems arise when building is allowed on an unstable area, like a barrier beach, and are compounded when the structures are erected to close to the high-water line. Prior to the construction of residences or commercial establishments, storms removed seemingly insignificant amounts of sediment. Once a premanent structure is present against which sediment loss can be directly measured, the sediment loss becomes alarming (at least to the owner of such a structure). In order to protect private property, demands

are soon made for "beach-stabilization" projects. This results in the construction of *groins* to rebuild the beach by slowing the longshore current. Using Fig. 9.1 to illustrate, the groin, by slowing the longshore current causes sediment deposition upbeach of the groin. Since the longshore current is deprived of its sediment at this point, but immediately reforms to the opposite side of the groin, it removes sediment from this area with no corresponding sediment deposition. The beach is therefore cut back immediately downcoast of the groin. With other structures present, additional groins must be constructed. Once this occurs, the beach will be destabilized immediately downcurrent of each new groin and another groin will be necessary. Consequently, once one groin is constructed, the community is committed to build a series of groins to stabilize the beach that the previous groins destabilized.

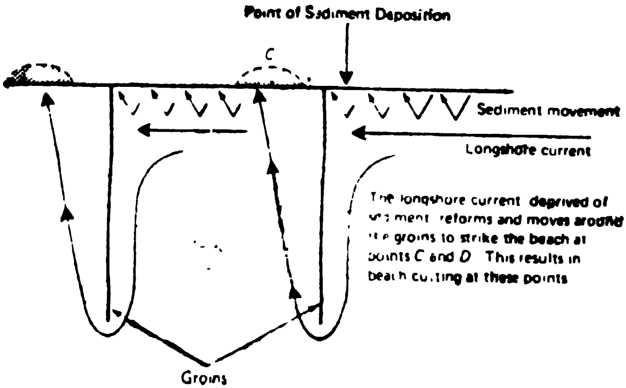


Fig. 9.1. Schematic illustration of the effect of groins on sediment transport.

Coastal Landfill

Salt marshes are both economically and ecologically vital to coastal and estuarine areas. They play an important role as storm surge buffers, erosion-control devices, sediment traps, and as oxidation basins that serve to break down deleterious materials prior to their entering the estuarine waters. They also act as wildlife habitats and estuarine nurseries. Although estimates vary as to the amount

of organic material produced, and thus available as food for estuarine food chains, their value is considerable. For example, it is estimated that Georgia marshes produce 4.4 to 8.9 tons (dry weight) of organic matter per acre per year ; Virginia marshes are estimated to produce 3.0 to 7.0 tons (dry weight) per acre per year and Long Island marshes to produce 2.3 to 3.7 tons (dry weight) per year. This compares very favorably to the 1 to 1.5 tons (dry weight) per acre per year yields of wheat production and the 0.33 ton per acre per year produced in the deep ocean. Salt marshes are, therefore, one of the most productive natural resources available in a time of dwindling food resources.

It is calculated that tidal currents transport 45% of this material into adjacent estuarine waters, where it forms the base of complex food chains. Since two-thirds of the total commercial fishery catch are estuarine-dependent species, it is estimated that each acre of salt marsh produces a tangible benefit of $78 annually.

In spite of their proved value, thousands of acres of salt marshes are destroyed annually. For example, 25% of the salt marshes in Suffolk County, New York, were destroyed between 1964 and 1971.

The major factors in marsh destruction are landfill operations to create waterfront real estate and deposition of dredge spoil. Regardless of the source, the destruction of marsh lands is an irreversible process that directly reduces the productivity of many coastal areas.

Effects on Man

The consequences of pollution on the human race are widespread and range from a reduction in the recreational value of beaches and waterways, to unaesthetic drinking water, to serious health hazards. Consequently, any of the practices discussed in the preceding sections will affect man to some degree. For example, any mechanism that serves to reduce the numbers of organisms in a natural food chain affects man not only by reducing the amount of

food available to the human population, but also by adversely affecting the economics of the commercial fishing industry. Thus practices as divergent as the ocean disposal of sludge, the increased mercury concentrations in fish, the release of heated effluent, and the construction of groins will all adversely affect the economic, recreational, and/or biological well-being of at least some segment of the human population.

Rather than consider each pollutant in detail, this section will discuss only selected examples of the consequences of pollution on man. The factors to be considered here will be the well-studied metals—lead, mercury, and cadmium—as well as pesticides, nitrate, and carcinogenic compounds found in drinking water supplies. For a complete survey of the impact of pollutants on man, the reader is referred to *Health Effects of Environmental Pollutants* by George L. Waldbott (see Suggested Readings).

Metals

The symptoms of lead poisoning include loss of appetite, weakness, and miscarriage, as well as lesions of the neuromuscular system, the circulatory system, the brain, and the gastrointestinal tract. Levels of lead in the blood of Americans range from 0.05 to 0.4 ppm. The threshold levels for acute lead poisoning range from 0.5 to 0.8 ppm. Since lead is absorbed from air, water, and food, it is obvious that many city dwellers exposed to gasoline fumes are presently absorbing lead at or close to toxic levels. Since lead levels in air, water, and food are increasing, it is expected that cases of lead poisoning will show a corresponding increase in the future.

Individuals vary in both their sensitivity and exposure to methyl mercury. For example, populations whose diets consist mainly of fish will have a high exposure to mercury. Symptoms of mercury poisoning include deafness, loss of coordination, insanity, and death. In addition, evidence indicates that methyl mercury may cause genetic damage. As noted previously, pickeral from the Great Lakes have

mercury concentrations as high as 5 ppm. Since there have been cases of human mercury poisoning at concentrations as low as 0.2 ppm, this necessitated the authorities in both Michigan and Ohio to ban fishing in not only Lake Erie but also in Lake Saint Clair, the Saint Clair River, and the Detroit River. In addition to the health hazard posed, the economic impact on Ohio's commercial fishing industry was considerable.

Recent U S. Geological Survey research has found cadmium levels to be above U.S. Public Health Service limits in the water supplies of 12 cities ; in addition, cases of fatal cadmium poisoning have been reported in Japan. Cadmium is toxic to all human systems and has been implicated in hypertension and in respiratory and kidney disorders. It also appears to have a genetic effect on experimental animals, inducing malformations in the upper jaws of newborn rats whose mothers had been exposed to cadmium in their food during pregnancy.

Cadmium, mercury, and lead are known to concentrate in food chains, and they are all found in human food sources. It is obvious that exposure can come from airborne as well as waterborne sources ; the danger of exposure to these materials is thus increased. The use and input of these materials into the environmental should be carefully controlled and curtailed.

Pesticides

Pesticides are known to be present in the body fat of human beings. The main source of these materials is through ingestion in food supplies. However, in some cases, pretreated water is known to contain various pesticides. Although all pesticides in use can be fatal in sufficiently large doses, lethal levels cannot be determined adequately, since many variables, such as age, health, sex, and diet, affect the toxicity of these materials.

Since the chlorinated hydrocarbons have only been in widespread use for the past 25 years, possible long-term, sublethal effects, principally carcinogenic and mutagenic in nature, have yet to become evident. It is known that pesticides such as DDT and

dieldrin are capable of producing malignant and benign tumors in various organs of experimental animals.

Nitrates and Nitrites

Increased nitrate levels in water supplies can be fatal to infants. At these levels the disease *methemoglobinemia* is induced by intestinal bacteria that have the ability to convert nitrate to nitrite. The nitrite is then absorbed into the bloodstream, where it binds with hemoglobin. This binding action effectively prevents the hemoglobin from accepting the oxygen that is necessary for respiration.

Carcinogenic Substances

Recent studies indicate that the chlorination of municipal waste-water may be responsible for the addition of chlorinated organic materials to a river system.

In some countries, the public drinking-water supplies are routinely contaminated with carcinogenic substances from the chlorination processes employed at water-treatment plants (pretreatment) prior to the distribution of the water to the consumers. It has been also demonstrated that carcinogens were not removed by the current water-treatment methods. However, these studies do not mean that water-treatment methods are futile. They do indicate that many treatment plants are currently inadequate and must be upgraded.

WATER POLLUTION AND HEALTH

The quality of domestic water supplies is an old problem. In *De architectura*, a work written between 25 and 23 B.C., Vetruvius Pollio, the great Roman architect and builder, gave numerous examples to show that bad water was injurious to health. Phythios, the Greek builder of the tample of Minerva in Priene on the coast south of Ionia, also dealt with this problem in a textbook on architecture. Clean water was just as difficult to guarantee 2,000 years ago as it is today. The Romans did not have filtration plants, chlorination

facilities, or similar modern equipment. They had to rely on local streams and springs or transport the water over long distances. The Roman aqueducts, a number of which are still in use today, provided clean water for cities. Where these sources were not available, wells had to be dug ; and to assure good water, they were planned by architects and builders of established reputations.

According to Vetruvius, the water at Susa, the ancient capital of Persia, was unfit for human consumption because its use resulted in tooth decay. It was the earliest reference to the effects of fluorine deficiency. In more recent times, *denti neri*, or black teeth, has been a distinguishing characteristic of the people living in the vicinity of Vesuvius and other areas of volcanic origin in certain parts of Italy. Dark or mottled teeth are characteristic symptoms caused by drinking water that contains an excess of fluorine.

Vetruvius also cited the case of a spring on the island of Chios that was said to confuse the mind. In the Alps there were springs whose water caused "thick necks", an obvious reference to goiter, caused by an enlarged thyroid gland, which in turn is caused by insufficient iodine in the water or diet. Both goiter and cretinism, a form of mental retardation associated with failure of the thyroid to develop, are still found in some Alpine valleys. Vetruvius warned against water containing too much or too little iodine. He also warned against water from springs in the vicinity or metal mining. He said that the water would be adversely affected by the minerals present in gold, silver, iron, lead, and copper mines.

Vetruvius recommended making chemical tests. One method was to sprinkle water on a bronze vessel. If it did not leave stains, the water was good. Another test was to boil the water in a kettle. If the sediment was sandy after cooling and decanting, the water was good. Vetruvius also suggested that vegetables such as peas and beans be boiled in the water, and if they did not become soft, the water was unfit for drinking and was suitable only for industrial purposes. The simplest and best test of all was to observe the inhabitants in the vicinity of the source. If they were strong

and healthy and were not afflicted by diseases of the feet and eyes, this could be taken as profit that the water was healthful and suitable for human consumption.

The effect of chemical pollutants on health is not well understood. Even information on the identity and amounts of the chemicals that are present in incomplete, although the use of chemical products everywhere is on the increase. Some natural waters are known to have injurious chronic effects from prolonged use. Therefore, chemical contaminants that may enter the water supply from sources such as sewage effluents, the recycling of treated wastes, or percolation of wastes into the underground water supply should be under suspicion until proved to be harmless by experiments with laboratory animals.

The appearance of foaming agents in well waters from the use of detergents containing nonbiodegradable surfactants was a warning of the potential dangers. The presence of 0.5 ppm of ABS (alkyl benzene sulfonate) in drinking water would not be acutely toxic, but it would indicate that at least 5 percent of the water is of sewage origin. Moreover, surfuctants are capable of solubilizing other compounds that might be harmful. The degradation products of surfactants and organic solvents have largely unknown biological properties.

For a long time, some scientists suspected that much of the drinking water contained organic chemicals other than those of biological origin. Frequent contaminants included two suspected carcinogens, chloroform and carbon tetrachloride, and several other organic chemicals of largely unknown physiological and health effects. The study turned up some surprising contaminants, like nicotine and vinyl chloride, another carcinogen.

Several waterborne infectious diseases are directly related to polluted water. In addition, the aquatic food chain acts to concentrate several toxic substances as it ascends from microorganisms through various predators and prey to fish eaten by seals, by

certain birds, or by people. Organochlorine and organomercury pesticides, PBCs, and some radioactive pollutants are concentrated this way.

Well water contaminated by nitrates from fertilizer runoff poses a hazard to health, particularly for infants.

The toxic and pathological effects of some heavy metal water pollutants have been tabulated in Table 9.1.

Table 9.1. Pathological effects of heavy metal water pollutants on man.

	Metal	*Pathological effects on man*
1.	Mercury	Abdominal pain, headache, diarrhoea, hemolysis, chest pain.
2.	Lead	Anaemia, vomiting, loss of appetite, convulsions, damage of brain, liver and kidney.
3.	Arsenic	Disturbed peripheral circulation, mental disturbance, liver cirrhosis, hyperkeratosis, lung cancer, ulcers in gastrointestinal tract, kidney damage.
4.	Cadmium	Diarrhoea, growth retradition, bone deformation, kidney damage, testicular atrophy, anaemia, injury of central nervous system and liver, hypertension.
5.	Copper	Hypertension, uremia, coma, sporadic fever.
6.	Barium	Excessive salivation, vomitting, diarrhoea, paralysis, colic pain.
7.	Zinc	Vomiting, renal damage, cramps.

8.	Selenium	Damage of liver, kidney and spleen, fever, nervousness, vomitting, low blood pressure, blindness, and even daath.
9.	Hexavalent chromium	Nephritis, gastro-intestinal ulceration, diseases in central nervous system, cancer.
10.	Cobalt	Diarrhoea, low blood pressure, lung irritation, bone deformities, paralysis.

LOSS OF RECREATIONAL AREAS

Beaches are closed when the bacteria count of water is too high, indicating pollution by fecal matter. Beaches are also closed when the water contains toxic substances or gives off a foul odor. In heavily polluted areas where algae have thrived and died, rotting mats of floating debris wash up on the shore. Solid wastes sometimes wash up also, and some oil spills have caused spektacular damage to valuable beach properties. Water containing considerable organic matter generally becomes depleted in oxygen as micro-organisms that feed on that material die and decay. Decay consumes oxygen, and desirable fish needing a relatively high oxygen level either die out or go elsewhere. Mercury pollution or pollution by PCBs also reduces the recreational value of a fishing lake. Resort owners, commercial fishermen, and the communities that benefit from such recreational activities suffer considerable economic damage from many types of water pollutlon.

WATER POLLUTION AND WILD LIFE

Fish Kill

A very interesting source of information about water pollution is that it affects aquatic life. Tens of millions of fish are killed each year by a wide variety of different pollutants from many different sources, municipal and industrial.

Crop poisons also occur from aerial spraying, copper sulphate applied to control algae in a ditch, discharge of zinc cyanide from the plating room of a chain company, discharge of acid water from the waste piles of a coal mine, detergent discharged from a chemical laboratory, chlorine escaping from a private swimming pool, gasoline from a pipeline break, endrin sprayed on a tomato field, alkyd base paint from the storm drain of a chemical company, fluid chicken manure from a poultry farm that reached the water after a waterline break, leak of wash water having caustic soda and sulfuric acid from a steel company plant, dairy waste, anhydrous ammonia refrigerant from a dismantled refrigeration unit, drainage from a solid waste disposal operation, oil from a tank car overturned in a railroad wreck, a fuel tank leak at an oil bulk station, and a thermal pollution incident.

There are many cases on record of the destruction of wildlife by polluted waters. Mass killing of fish was among the earliest and most dramatic results of indiscriminate pollution of water. The cases are too numerous to list. During the ten-year period from 1980 to 1989, a total of 345 million fish were reported killed in more than 6,200 cases of pollution, the contamination coming from diverse sources which vary from year to year.

Red-Tide

It must not be assumed that all mass die-offs of wildlife are caused by man-made pollution. Large numbers of ducks are sometimes killed by a type of botulism that develops in marshy areas at certain times of the year. For example, 140,000 ducks died of botulism in California during 1970. In the fall of 1964, approximately 50 million dead anchovies piled up in the harbor at Santa Cruz, California. The fish were victims of the "red tide" that periodically assaults areas of the Pacific coast. When conditions are favorable for a buildup in population of the red-tide organism, the single cell plantlike animals—or animal-like plants—sometimes have disastrous effects on fish, apparently because they become so numerous that they rob the water of oxygen. An infestation was

attributed with killing more than 200 tons of commercial fish near the coast of southern California. A number of similar kills of fish and shellfish have been reported. Some of the marine life may have been killed by the poisonous substance *saxitoxin*, produced by the red-tide organisms.

Black Tide

Pollution of the aquatic and marine environment by oil can occur almost anywhere at any time. There are many examples. A dramatic incident was that of the tanker *Torrey Canyon* when she struck a reef off the southern tip of the British Isles in March of 1967. She was carrying 118,000 tons of crude oil. The tanker began to split apart about a week after going aground, and the effects of oil-polluted beaches on a disastrous scale was realized for the first time.

Oceangoing tankers are a continuing source of oil pollution. About 1 billion tons of petroleum products are shipped worldwide each year. The tonnage is increasing annually with the construction of tankers of greater size for improved efficiency. If spills were only 0.01 per cent of the petroleum transported, they would amount to more than 20 million gallons polluting the sea every year.

The *Torrey Canyon* was the largest oil spill up to that time. The pollution caused widespread destruction of many forms of marine life despite strenuous efforts to clean up the spill. The Nature Conservancy in London reported that 7,000 oil-logged birds had been captured and treated but that only a few hundred lived. The St. Agnes Bird Observatory estimated that 40,000 seabirds died. Within two weeks, one million gallons of twelve different detergents had been used in an effort to clean up the spill. Most of the detergents consisted of 80 per cent aromatic solvent similar to paint thinner) and 20 per cent surfactant. But the detergents themselves were toxic, and the mixture of emulsified oil and detergent was far more toxic than the oil itself. In addition to the catastrophe to marine life and fisheries, the direct monetary cost of the cleanup was about 8 million

dollars, according to a British government report. Supertankers twice the size of the *Torrey Canyon* are already in operation.

Refineries and oil drilling operations are other potential sources of oil pollution. The blowout of a well in Santa Barbara Channel in January 1979 resulted in a leakage estimated at 500 barrels per day, which amounted to approximately 2,36,000 gallons over a ten-day period. Damage to sea life including marine birds was extensive and the incident had a shocking impact on the aesthetic qualities of the nearby coastal area. Offshore drilling continues in several areas along the nation's coastlines and is an ever-present threat that requires constant vigilance. Pollulion of the seas with oil from all sources has been a major global problem.

ATMOSPHERE IN THE SEA

Without dissolved carbon dioxide and oxygen, it would not be possible for the profusion of aquatic (fresh-water) and marine life to exist. The high solubility of carbon dioxide in water has been of great importance in promoting photosynthesis by phytoplankton and, consequently, has been beneficial to all organisms in the food chain. The relatively low concentration of oxygen in water compared to air has been a disadvantage to aquatic and marine animals that depend on gills or similar arrangements for obtaining oxygen from water and accounts for the greater efficiency of air-breathing animals. However, some of the disadvantages could be overcome by the intricate structure of gills and mechanisms for gas exchange. The increase in solubility of oxygen and carbon dioxide in water at low temperatures has been favorable for the development of marine life and explains why many of the world's most productive fisheries have been in cold waters.

The bodies of water have been in a state of equilibrium with the atmosphere and the earth because the solubility of the gases increases as the water temperature and salinity drop. However, we do not find the same proportions of the gases in water as in the air, due primarily to differences in solubility. Pure water exposed to the

atmosphere is having, *by volume*, about 2 percent nitrogen, 1 per cent oxygen, and .05 per cent carbon dioxide at 0° and atmospheric pressure. Compared to nitrogen and oxygen, the amount of carbon dioxide has been proportionately much higher than in air. However, the concentration of oxygen and carbon dioxide in natural waters has been highly variable. The differences have been largely the result of the growth of algae and other aquatic organisms and the stagnation or mobility of the water.

Carbon Dioxide

Carbon dioxide in natural water comes primarily from two sources : from dissolved gas from the atmosphere, and from carbon dioxide liberated by organisms during respiration. The concentration has been varying from a fraction of a part per million to about 20 milligrams per litre (about 20 ppm or .002 percent).

Water has been capable of absorbing carbon dioxide by entering into a chemical reaction with it, forming carbonic acid :

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3}$$

As the reaction is reversible, the carbonic acid acts as a reservoir which makes some carbon dioxide available for plants when the dissolved gas nears depletion. Some of the carbonic acid dissociates (ionizes) with the formation of hydrogen ions and bicarbonate ions :

$$\underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-}$$

And some of the bicarbonate ions dissociate to form more hydrogen ions and carbonate ions :

$$\underset{\text{bicarbonate ion}}{HCO_3^-} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{carbonate ion}}{CO_3^{2-}}$$

The three reactions have been in equilibrium, shifting to the right or left depending on the withdrawal or addition of ions by organisms, the acidity or alkalinity of the water, and the temperature In the ocean the concentration of bicarbonate ion has been an average of about 0.014 percent.

Some investigators reveal that a small increase in air temperature could make a great increase in atmospheric carbon dioxide, resulting in a catastrophic effect on climate if there were no moderating influence. But others say that control mechanisms may exist in the oceans, which have been capable of absorbing large amounts of carbon dioxide in chemical combinations. A "feedback" mechanism may exist in the atmosphere itself, for an increase in temperature has been apt to cause an increase in cloudiness, resulting in a smaller amount of solar radiation reaching the surface of the earth.

Oxygen

In a body of water having diversified biota, the oxygen content has been in a condition of unstable equilibrium. Some of the oxygen has been added by direct absorption from the air and some of it comes from the oxygen given off by plants during photosynthesis. Absorption of oxygen from the atmosphere could be aided by surface agitation caused by wind and waves, but such action may also reverse the process of releasing oxygen to the atmosphere when the water becomes supersaturated. Oxygen could be removed from the water by respiration of organisms and by the oxidation of dead organic material during its decomposition.

While aquatic plants are able to absorb carbon dioxide from the water for use during photosynthesis, oxygen gets released in the dissolved state, except when the water has been supersaturated with oxygen, in which case gaseous oxygen has been liberated. Oxygen is released during the first (energy capture) phase of the photosynthetic process called *photolysis*, during which the action of light energy on the chlorophyll indirectly brings about the decomposition of water into its components, hydrogen and oxygen. As photolysis can take place only in the light, the production of oxygen is limited by the amount of sunlight available and can occur only in the region called the photic zone. The total oxygen productivity of an ecosystem could be determined by the amount of solar energy reaching the organisms, by the photosynthetic efficiency of the plants, and by physical factors such as temperature that affect the rate of photo-

synthesis. A covering of ice and snow is able to reduce both the penetration of light and the absorption of oxygen.

As the temperature goes down, the oxygen capacity of the water increases. Cold water at 39°F can be able to hold 1½ times as much oxygen as warm water at 75°F. The saturation level at 0°C in fresh water has been about 15 ppm, but the concentration may increase to two or three times as much when the rate of photosynthesis has been high during daylight hours, and may fall far below the saturation level when photosynthesis declines at night.

Depletion of Dissolved Oxygen

Bacterial decomposition of organic matter may deplete the dissolved oxygen in stagnant deep water during the summer when there is an over-abundanee of phytoplankton and other aquatic life. In like manner, the decomposition of organic matter in sewage wastes depletes the oxygen content. Organic pollution from either natural or human sources is sometimes expressed as the amount of oxygen needed by microorganisms to decompose the organic material. An evaluation could be done by determining the amount of oxygen used up over a period of 5 days in the laboratory. This is termed as the B.O.D. (*biochemical oxygen demand*). The B.O.D. is an indication of the amount of organic material present in the water or waste water.

A problem arises if there has been a deficiency of oxygen to the extent that anaerobic conditions prevail. Whereas the aerobic oxidation or organic material results in generally harmless end products, anaerobic decomposition produces substances that have been both objectionable and toxic.

Oxygen deficiencies have been injurious to fish. A reduction in concentration of dissolved oxygen (D.O.) to about 3 milligrams per litre or less makes delayed hatching of eggs, reduced size and vigor of the embryos, deformities in the young, interference with the digestion of food, accelerated clotting of blood, reduced growth rate, poor utilization of food, impairment of swimming speed, and a

decreased tolerance to toxicants. The lethal effect of low concentrations of dissolved oxygen appears to get enhanced by excessive carbon dioxide and ammonia as well as by cyanides, zinc, lead, copper, and cresols (cresylic acids).

Global Oxygen

Organic pollutants make such demands on the oxygen content of natural waters that serious problems often ensue. In many cases the oxygen level has been below that needed for the survival of fish and other aerobic organisms. On a global basis, however, the oxygen reserve has been less critical. There has been no reason to assume that the earth's oxygen supply will be depleted in the foreseeable future, even though at various times and places organic waste can place an excessive burden on its immediate availability.

10

Adverse Effects of Specific Pollutants

INTRODUCTION

In this chapter, the adverse effects of the following specific pollutants have been described in brief :

1. Mercury
2. Lead
3. Detergents
4. Chlorination
5. Nitrates
6. Oil
7. Pesticides (including DDT).

MERCURY

Natural Occurrence and Properties

It is to be expected that some mercury will occur in the environment, because it is a naturally occurring element. Most mercury found in nature has been combined with other elements : only rarely has been it found in the elemental form. Mercury compounds, like many others, are dispersed throughout rocks, soil, air, water, and living organisms by a complex system of physical, chemical and biological processes.

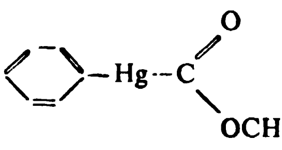
Mercury and its compounds have been used by man during much of his existence. It has been one of the few elements known in biblical times. Its chemical and physical properties make it an attractive metal for use in scientific and industrial applications.

Mercury has been used in a wide variety of ways. The largest user has been seen to be the chlor-alkali industry, which produces chlorine (Cl_2) and caustic soda ($NaOH$) by the electrolysis of salt ($NaCl$) solutions. The function of mercury in this process is to serve as the cathode of the electrolysis cell.

The second greatest consumption of mercury has been in the production of electrical apparatus. This application encompasses a large variety of uses.

The use of mercury and its compounds as fungicides constitutes the third largest category of mercury consumption. In this application, use is made of the toxicity of the substances toward living organisms. These substances have been used to destroy fungi in the paint, pulp and paper, and agricultural industries. Mercury compounds have been added to paint that is to be used in humid regions to act as a latex preservative and a mildewcide. Paints for use on ships must contain "anti-fouling" agents to prevent barnacle growth. Mercury oxide (HgO) is often used in this application. Mildew proofing of marine paints has been also necessary, and phenyl mercuric acetate or its derivatives have been commonly used.

This last compound, phenyl mercuric acetate (PMA), has been the most important organomercury compound of commerce. The formula for this widely used substance has been as follows :

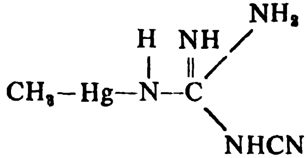


The paper and pulp industry has also made use of PMA to prevent the growth of slime on wet paper pulp during processing or storage. Other organomercury compounds have also been used in smaller amounts for the same purpose.

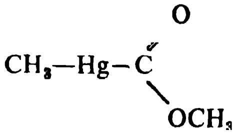
Agricultural industries have been using organomercury compounds as ***seed dressings*** to inhibit the growth of fungi on agricultural seeds. Some typical compounds used for this are :

Methylmercurynitrile $CH_3-Hg-C\equiv N$

Methylmercurydicyandiamide



Methylmercuryacetate



Ethylmercurychloride $C_2H_5-Hg-Cl$

Elemental or metallic mercury finds use as a catalyst in some chemical manufacturing processes, especially in the manufacture of vinyl chloride, the base for many plastics. It was mercury effluent from a vinyl chloride plant that caused the largest known epidemic of mercury poisonings in Minamata Bay, Japan (1953-60). Metallic mercury is also used in thermometers and temperature recording devices.

Sources of Hg Pollution

Industry has been the largest user of newly mined mercury. Since 1970, much has been done to eliminate waste discharges of mercury from industrial sources.

The chlor-alkali industry has been the largest industrial user. Theoretically, no mercury is consumed during the process of producing Cl_2 or caustic soda. Actually, however, losses of mercury occur. Some gets lost to the products, some leaves with effluent water, and some gets lost through air ventilation systems. The operating conditions of the electrolysis cells result in a loss of 0.1-0.5 lbs. of mercury for every ton of Cl_2 produced. Most of this loss ultimately shows up in the waste-water discharges from the plants.

The use of PMA by the pulp and paper industry for in-process slime control has resulted in PMA discharges with waste water. The incineration of paper produced when PMA was used constitutes a possible source of airborne mercury pollution, because trace amounts of mercury remain in such paper. Commercial laundries, especially those with a diaper service, employ PMA to suppress mold.

A current area of great concern involves the use of mercury compounds as seed dressings in agriculture. The amount of mercury in the seed dressing formulation has been small, but the effect has been large, because the seed dressing has been applied to a large volume of seed that has been subsequently sowed over millions of acres, which results in an extremely widespread dissemination of the mercury compounds. Also, there has been enough evidence suggesting that the mercury undergoes translocation in plants (a serious effect discussed later).

In addition to losses of mercury from direct usage, some gets released in the combustion of coal and petroleum products. A number of investigators have found mercury levels averaging about 1 ppm in coal This amount seems to be small, but on a worldwide basis the annual world production of fossil fuels to about 5×10^9 metric tons could, upon combustion, release 5000 metric tons of mercury.

Other human activities contribute to mercury levels also. Sludge from sewage plants is having enough mercury, in some cases, to make it unsuitable for use as a soil fertilizer. The other sources are such commonly used materials as disinfectants, pharmaceuticals, and paints.

Mercury Amplification in Food Chain

Mercury is regarded to get into the food chain by two routes, water and seed dressings.

The report on fresh water fish from Lake Erie and the St. Clair River indicated the presence of mercury at concentrations given in Table 10.1.

Table 10.1. Mercury Levels in Freshwater Fish

Fish	*Mercury level (ppm)*
Walleye pike	1.4 to 3.57
Sucker	0.88
Northern pike	0.64
White bass	0.53 to 0.80
Channel catfish	0.32 to 1.80
Coho salmon	0.24 to 0.96
Carp	0.08 to 0.28

Further studies on fish have revealed that all fish not directly exposed to mercury during their growth still consistently are having mercury levels in the low range of 0.005-0.075 ppm. Further, the rates of mercury accumulation get varied significantly with different conditions and between different organs.

Another fact determined by studies involving fish has been that most of the mercury present in living tissues has been in the form of organic compounds and primarily in the form of methyl mercury.

It is becoming evident that mercury is concentrated in living tissues. This concentration process has been involving food chains in which small organisms containing mercury are ingested in quantity by larger organisms, which, in turn, are eaten by still larger ones and so on. The organisms further up the chain obtain all the mercury collected by those down the chain. This amplification can give rise to high levels of mercury in the tissues of animals near the top of the chain. Man is at the top of every food chain in which he is involved.

In the case of fish, tiny marine diatoms are having mercury compounds adsorbed to their surfaces. Fish, upon eating these or other small animals or plants, concentrate the mercury in their tissues. Some mercury also gets absorbed by fish through their gills from surrounding water. Because of this process, the tissue of the fish has a higher mercury level than the surrounding water. For

example, trout exposed to mercury levels of 0.1 ppm for 1 hour per day has been reported to be having a tissue level of 4 ppm of mercury after 10 days exposure.

Some evidence reveals that mercury from seed dressings can undergo translocation in plants and animals. Translocation in plants has been involving the transfer of mercury from seed to crop. In animals, the process makes mercury to move to various parts of the animal or into products obtained from the animal (eggs, for example). It has been possible for mercury to get translocated from grain seed to the harvested grain, then to a hen, and finally to eggs. Data exist to support this idea.

It should be noted that mercury from seeds does appear in grain through translocation and eventually finds its way into animal tissue by way of food chains.

Mercury Poisoning and Biological Methylation

The occurrence of mercury poisonings has been well-documented fact. Widespread incidents have been reported only during the last two decades. These incidents occurred due to the eating of mercury-contaminated fish or the eating of seed grain treated with mercury compounds.

Although the toxic action of mercury in the body has been not completely understood, recent research has revealed some information about the problem. The primary facts determined have been as follows :

1. All mercury compounds have been toxic to the body when present in sufficient quantity.
2. Different mercury compounds exhibit somewhat different characteristics of toxicity, distribution, accumulation, and retention times in the body.
3. Certain biological transformations may occur in the environment or the body which change mercury compounds of one type into other types.

4. The ultimate effects of mercury in the body appear to be inhibition of enzyme action and cellular damage caused by the ability of mercury to bind tightly with sulfur-containing groups in molecules which are present in both enzymes and cell walls. Such binding is able to inactivate enzymes and upsets chemical reactions which they catalyze in the body. The membrane properties of cell walls get disrupted by the binding of mercury, and normal cellular activities are inhibited.

5. The damage done to the body by mercury has been generally usually permanent. There has been no known effective treatment.

The behavior of mercury compounds in the body has been usually discussed in terms of three different classes of mercury compounds. Inorganic mercury includes elemental (metallic) mercury and its salts, such as chlorides, oxides, and so forth. Organic mercury compounds include the two other classes. The arylmercurials are having aromatic hydrocarbons as part of the molecule, while alkylmercurials contain aliphatic hydrocarbons.

Inorganic mercury tends to accumulate in liver and kidney tissue. This causes damage, but also offers a means for rapid elimination through the urinary system. Metallic mercury vapor is having a great capacity for diffusion through the lungs into the blood and then into the brain, where serious central nervous system damage takes place. Normally, inorganic mercury, in the form of compounds, does not remain in the body long enough to accumulate to dangerous levels.

Upon introduction into the body, arylmercurials break down readily into inorganic mercury compounds and behave as indicated above. The compound PMA, previously discussed, behaves this way.

Alkylmercurials represent the greatest health hazard due to a number of reasons :

1. They easily penetrate into and accumulate in brain tissue. This is accomplished in part since they diffuse easily through biological membranes.

2. They exhibit long retention times in the body. This makes the mercury concentration to build up even though dosages may be low. The estimated half-life of these compounds in the body has been 70 days.

3. Alkylmercurials can be produced from inorganic mercury by the action of certain anaerobic microorganisms. This transformation occurs readily in the mud of rivers and lakes. The extent to which it takes place in the human body is not known, but microorganisms found in some animal intestines are able to accomplish the feat.

The classes of mercury and their relationships to each other have been given in Fig. 10.1.

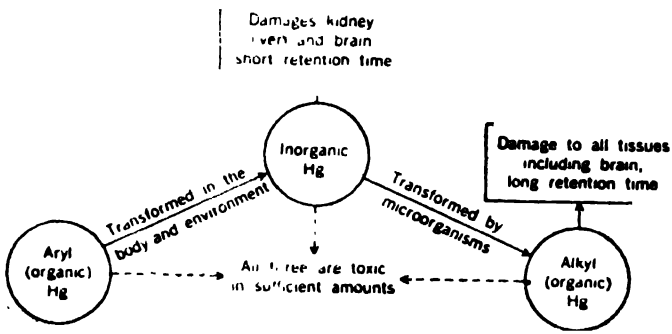


Fig. 10.1. Relationships between classes of toxic mercury.

Methylmercurials appear to be the most dangerous and toxic of the mercury compounds. They can enter the environment in several ways—directly, indirectly, intentionally, or unintentionally. A direct and intentional route could be represented by the use of methylmercurials on seed. A direct but unintentional route has been provided when methylmercurials used in industry or formed as a waste product of industrial processes are dumped into natural

waters. The episode at Minamata Bay was caused in this way. An indirect route has been provided when other mercury compounds get methylated (transformed) by biological organisms.

A very serious example of the latter route has been involving inorganic and phenyl mercury from industrial sources. The metallic mercury or compound, upon settling into the bottom mud of lakes, gets converted by anaerobic microorganisms into CH_3Hg^+ or $(CH_3)_2Hg$. This latter compound has been very volatile and escapes from the mud into the water. The $(CH_3)_2Hg$ has been stable in alkaline solutions, but when exposed to acidic surroundings, it changes to CH_3Hg^+. This ion has been soluble in water and concentrates in living organisms, usually appearing in body lipids. This accumulation occurs due to direct absorption of the ion or an amplification by a food chain process.

Sources of environmental mercury could be easily documented, but a close examination shows the complexity of dealing with mercury pollution. The complexity has been illustrated by the following facts :

1. Mercury has been volatile and can contaminate the air.
2. Mercury has been a liquid and can spread over surfaces in small droplets, which prove very difficult to collect.
3. Mercurials undergo translocation in plants and animals.
4. Mercury or mercury compounds could be converted by microorganisms, present in river and lake mud, into highly toxic methyl mercury compounds which are amplified by common food chains, including man's.

In order to prevent environmental pollution by mercury, following facts must be kept in mind :

1. The use of all alkyl mercury pesticides must be terminated.
2. The use of all other mercurial pesticides should be restricted to areas of demonstrated need.
3. All industrial users of mercury must be required to reduce discharges of mercury into the environment to levels approximating normal background levels.

The implementation of the above recommendations will not completely solve the problem. Sufficient mercury contamination has been present in the bottom muds of rivers and lakes to continue to yield highly toxic CH_3Hg^+ into the waters for years to come. Some sort of decontamination is needed. Large scale pilot experiments on decontamination methods have been postulated :

1. Bottom sediments get covered with fresh, finely divided materials having high absorption capabilities.
2. Bottom sediments get buried under inorganic, inert materials.
3. The mercury-containing bottom sediments have to be removed by dredging or pumping.

LEAD

Introduction

Lead pollution has been a problem which has been involving air, water, and soil. The lead pollution is increasing more rapidly in the air than in soil and water.

The earth's crust is not having a particularly large amount of lead (about $2\times10^{-5}\%$). Soil generally has small quantities of lead compounds.

The lead concentration of an area has been found to depend upon the geology of the area and the proximity to sources of lead pollution. The average lead content of the earth's crust in parts per million has been 16 ; however, levels of several thousand ppm have been found near smelters.

The natural background level of lead and its comounds in air must be very low due to low vapor-pressure values.

The quantities of lead used in various applications have been given in Table 10.2. The production of lead storage batteries for automobile use consumes the largest quantity of lead annually. Both metallic lead and its compounds have been used in this application. The electrodes of a typical battery are having an inactive

supportive structure called a grid. This structure is made of a lead alloy having 93% lead and 7% antimony. It provides mechanical support for the active battery ingredients and a path for the electrical current. The active portions of the battery consist of lead dioxide (PbO_2) and lead metal, which get bonded to the grid.

Table 10.2. Quantities of Lead Used

Application	*Percentage of total used*
Storage batteries	43.1
Metal products	26.2
Chemicals	20.1
Pigments	7.5
Miscellaneous	3.1
Total	100.0

Many metal products are having lead. A partial list consists of :

1. Ammunition
2. Bearing metal
3. Cable covering
4. Caulking substances
5. Pipes, traps, and bends (plumbing)
6. Sheet lead
7. Solder
8. Type metal

Some of these products have been produced from pure lead that is cast, rolled, or extruded into various shapes. Most, however, are made from lead alloys. Solder is having 50-95% lead, the remainder being tin. Type metal, used in the printing industry, has been an alloy of lead, tin, and antimony. A common formulation used in type metal contains 85% lead, 12% antimony, and 3% tin. Bearing metal is an alloy containing lead and antimony. Lead shot contains 0.1-0.2%

arsenic added to increase hardness and the spherical nature. Low-melting alloys, for use in fire alarms, automatic fire sprinklers, and electrical fuses, are alloys of lead containing bismuth, cadmium, or mercury.

The use of nonalloyed lead has been primarily limited to products that must resist corrosion. Pure lead finds use in pipe designed to carry corrosive chemicals, in sheets used to line sinks or vats exposed to corrosive substances, and as a covering for electrical cable used underground or under water.

Of the total lead used in the manufacture of chemicals, 99.8% went into the production of a single compound, tetraethyl lead, the popular anti-knock additive for gasoline.

Lead compounds find use as paint pigments because they are having low water solubilities, good covering power, and they exist in a variety of colors. The most widely used compound has been "white lead," $Pb(OH)_2.2PbCO_3$. "Red lead," Pb_3O_4, is a bright red powder used as a pigment in corrosion-resistant paints. An attractive yellow color has been produced by the inclusion of "chrome yellow," $PbCrO_4$, in paint formulations.

An interesting use of lead has been production of pottery glaze. A glaze has been a thin layer of glass fused onto the surface of clay objects. The main ingredient of ceramic glazes has been silica, which reacts with other oxides to give complex silicates (glasses). The lead compound PbO is added because it gives the final glaze attractive properties unattainable with other oxides.

Sources of Airborne Lead Pollution

The amount of lead in the air has increased markedly as the result of man's activities. This fact is dramatically demonstrated by a study of ice from northern Greenland. Samples of ice taken from various depths were analyzed for lead. It was found that lead levels in the ice (corresponding to atmospheric levels) have increased markedly since the industrial revolution and very sharply since 1940.

Atmospheric lead concentrations in urban areas have been 5-50 times that of nonurban areas.

Lead emissions into the atmosphere have been of two types, particulates and gaseous compounds. Gaseous emissions are generated primarily by the combustion of gasoline additives, tetraethyl lead and tetramethyl lead, in automobile engines. Particulates represent the form of emissions from most other sources.

Gasoline combustion accounts for the vast majority (98.2%) of all atmospheric lead pollution. The chemical route followed by these additives during gasoline combustion results in the emission of many different lead compounds in automobile exhaust. The two principal lead compounds emitted have been PbBrCl and PbBrCl. 2PbO.

Halogen containing compounds have been produced due to the presence of chemical scavengers in the anti-knock fluid added to gasoline. The active anti-knock agents in the fluid have been tetraethyl lead [$Pb(C_2H_5)_4$], tetramethyl lead [$Pb(CH_3)_4$], or a combination of both. Scavengers have been added to chemically combine with any lead compounds left in the engine because of combustion of the anti-knock agents. These compounds, which would change to engine-damaging metallic lead if left behind, combines with the scavengers and form compounds that are gases at operating engine temperatures. These gaseous compounds then exit with the rest of the exhaust products. The two main scavengers used have been ethylene dibromide ($C_2H_4Br_2$) and ethylene dichloride ($C_2H_4Cl_2$). A typical additive mix for automobile gasoline is having 62% tetraethyl lead, 18% ethylenedibromide, 18% ethylenedichloride, and 2% other ingredients.

The variety and relative amounts of lead products contained in automobile exhaust are shown in Table 10.3. The first column shows the amount of each lead compound present in exhaust immediately following discharge. The second column shows the amount of each compond present 18 hours after discharge. The 18-hour figures

indicate that the lead compounds probably undergo reactions when released into the atmosphere, because they were obtained by collecting the exhaust in a black bag filled with clean dry air and then analyzing the mixture 18 hours later. These results show that lead carbonates, oxycarbonates, and oxides may be important substances to consider when the health effects of lead pollution have to be investigated.

Table 10.3. Lead Compounds in Auto Exhaust

	Percentage of total lead Particles counted in exhaust	
Lead Compound	*Zero times*	*After 18 hours*
PbBrCl	32.0	12.0
PbBrCl-2PbO	31.4	1.6
$PbCl_2$	10.7	8.3
Pb(OH)Cl	7.7	7.2
$PbBr_2$	5.5	0.5
$PbCl_2.2PbO$	5.2	5.6
Pb(OH)Br	2.2	0.1
PbO_x	2.2	21.2
$PbCO_3$	1.2	13.8
$PbBr_2$ 2PbO	1.1	0.1
$PbCO_3 \cdot 2PbO$	1.0	29.6

Although major attention has been given to the contribution of gasoline combustion to atmospheric lead pollution, the other sources should not be overlooked. Though they contribute only a small percentage of the total lead pollution, they can become extermely important as point-sources in localized areas. Smelters can produce high levels of lead in air and soils located in their immediate vicinity. Concentrations of lead as high as several milligrams per cubic metre have been observed at ground level downwind from smelters.

Sources of Water-borne Lead Pollution

Public water supplies in most countries rarely contain clinically significant quantities of lead. Most samples with high levels have been taken from waters located near metal working industries.

Some serious outbreaks of lead poisoning occurred in Europe a number of years ago. The source of the lead was found to be lead pipe used in interior and exterior plumbing. The hard waters contain carbonate and sulphate ions which react with lead to form a water-insoluble protective coating of $PbCO_3$ and $PbSO_4$.

Two problems similar to the one of lead in water have recently become of interest. These problems involve moonshine whiskey and glazed ceramic containers.

The consumption of illegally produced whiskey has been a cause of lead poisoning in some parts of the world. The source of this lead in whiskey is lead solder used in the tubing of distillation units, and lead-containing automobile radiators used as condensers.

Lead-containing ceramic glazes have been a serious source of lead poisoning when used on containers for foodstuffs. It has been found that highly acidic liquids such as apple juice may dissolve the glaze and release lead into the liquid if the glaze is not properly formulated and applied.

A two-year-old Montreal boy died in 1970 as a result of drinking apple juice left standing in a handmade earthenware jug. Subsequent tests showed that juice left in the jug for 3 hours acquired a lead concentration of 157 mg/*l*. After 3 days the level was 1300 mg/*l*.

Lead in the Diet

The diet has been the principal source of lead for the general population. All natural foods are having small quantities of lead, and some additional lead may be picked up during the preparation of foods. Acidic foods in particular can leach lead from cooking, serving, and storage utensils made from lead-containing alloys or glazed pottery.

Soils in some areas have been still heavily contaminated with the stable compound lead arsenate, which was a widely used pesticide

prior to World War II. Its use has been discontiuned in favor of organic pesticides in many areas.

Limited studies of crops growing near highways suggest that, other variables being equal, lead levels in plants decrease exponentially with distance from highways, which provides more evidence against the automobile.

Another dietary problem has been possible among small children who are known to have a penchant for nibbling on materials not normally considered part of a well-rounded diet. In many countries lead is still used as an ingredient or interior house paint. Today nontoxic titanium compounds are also used for interior paints, and lead is restricted to exterior use. Children living in pre-1940 structures have suffered lead poisoning from eating flaking paint. Children between the ages of 1 and 6 years are the main victims, and 85-90% of the cases involve youngsters in the 1-3 year age group.

A serious dietary problem has been created when wild waterfowl ingest spent lead buckshot. The situation has been alarming in some areas : the resulting lead toxemia is responsible for an estimated 2-3% loss of waterfowl annually. The heaviest duck mortality from this source has occurred along the Mississippi flyway.

The chemical form of lead has beeen an important factor which is affecting its biological behaviour in the body. Organic lead, compounds, such as tetraethyl lead, get readily absorbed by the body through the skin or mucous membranes. This is a serious problem only to a small group of occupationally exposed workers, such as those involved in the manufacture of such compounds. Lead compounds used in gasoline, although organic, are not pollution hazards in the organic form as they are changed to inorganic forms during gasoline combustion. They get released into the atmosphere as these less hazardous compounds. Inorganic lead gets absorbed primarily through the gastrointestinal and respiratory tracts and is the main source of lead for the body.

Not all inhaled or ingested lead gets absorbed or retained by the body. Approximately 5-10% of that ingested gets absorbed from the gastrointestinal tract, and about 30% of that inhaled gets absorbed from the respiratory tract. Of the 30% absorbed through respiration, only 5% gets retained, and this amount has been a function of particle size of the inhaled material.

The toxic action of lead in the body is traced in part to an enzyme inhibition by the Pb^{+2} ion. The inhibited enzyme has been one necessary for the formation of hemoglobin. The inhibition has been the result of a strong interaction between Pb^{+2} and the sulfur groups of some amino acids of the enzyme. This may not be the only toxic effect.

The lead retained in the body from both air and dietary sources accumulates predominantly in the skeleton (90-95%). The bones serve as accumulation sites due to the similarities between the Ca^{+2} ions of bones and the Pb^{+2} ions. The total lead body pool for a 150 lb. man is 100-400 milligrams.

Evidence obtained from animal experiments reveals that there has been a continuous turnover of lead in the body, so measured concentrations tend to reflect the current degree of exposure. The biological half-life of lead in human bones has been estimated to be 2-3 years.

An unpleasant aspect of bone-accumulated lead has been that it may get remobilized and sent to other parts of the body long after the initial absorption. This remobilization can take place during feverish illness, because of cortisone treatment and because of old age.

Because the determination of lead in bones has been somewhat difficult, the concentration of lead in blood or urine has been commonly used as an indication of total lead in the body. The blood level appears to be a more reliable indicator than the urine level. Estimates vary concerning the exact level of lead in the blood necessary to cause the appearance of the symptoms of clinical lead

poisoning (plumbism). In adults these levels have been generally in the range of 60 to 100 micrograms (μg) per 100 ml of blood.

Table 10.4 gives standards for occupationally exposed adults. The lead concentrations in blood are divided into four categories—normal, acceptable, excessive, and dangerous. The significance of these categories becomes apparent when the lead levels have been compared to those found in blood samples collected from various segments of the general population.

Table 10.4. Four Categories of Blood Lead Concentrations in Adults

Category	*Blood Lead Level (μg per 100 ml)*	*Description*
A (normal)	<40	Normal population with no occupational or abnormal exposure.
B (acceptable)	40-80	Increased absorption resulting from occupational or abnormal exposure which is occupationally acceptable.
C (excessive)	80-120	Increased absorption from excessive occupational or other exposure which may be associated with mild symptoms or signs, or, rarely with severe symptoms or signs. These levels are unacceptable.
D (dangerous)	>120	Dangerous absorption from occupational or other exposure in which mild and severe symptoms and also long-term after-effects are increasingly probable.

Solutions to Lead Poisoning Problems

As the major source of lead pollution in air has been automobile exhaust, an obvious solution to this problem is to get the lead out (of gasoline).

The major sources of lead poisoning today have been still old paint and industry. Solutions to these problems include education programs directed at the hazards of old paint, strict housing codes to prevent occupancy of hazardous dwellings, and better enforcement of existing safety standards directed at industry.

DETERGENTS

Detergents have attracted special attention in many countries because of a variety of pollution problems involving their constituents.

According to a rigorous definition, a detergent may be defined as anything that behaves as a cleaning agent. This would include such materials like old-fashioned lye soap, alkaline dishwashing compounds, and solvent cleaners.

A more limited definition has come into common use, which limits detergents to those cleaning agents that include as part of their chemical makeup *petrochemical* or *other synthetically-derived surfactants*. The surfactants provide much of the cleaning power found in these detergents.

The appearance of bubbles and foam on a glass of water drawn from the kitchen tap was the first indication to many people that the domestic water in some areas was not very pure. The frothy "head" on a glass of drinking water was caused by the presence of *surfactants*. The term is a contraction of "surface active agent." Surfactants increase the wetting and cleaning power of water. They are the principal active ingredients in bath soap, toothpaste, shaving cream, shampoo, dishwashing compounds, detergents, and cleansing agents of various kinds. The largest use for surfactants is in household detergents, but there are also many industrial applications.

Detergents generally consists of a "surfactant" or surface-active agent and a number of "builders." The surfactant lowers the surface tension of the liquid in which it is dissolved by concentrating at surfaces and interfaces, and its cleansing properties arise from its

ability to replace dirt on surfaces by being preferentially absorbed at surfaces and by helping the dirt to be carried away as a stabilized emulsion or suspension. The builders sequester calcium and magnesium ions that would interfere with the surfactant ; they also maintain a proper level of alkalinity in the solution and help keep dirt in suspension.

Surfactants generally consist of polar or hydrophilic groups (such as COO^-, SO_3^{2-}, or NH_4^+) that are soluble in water and oily or lipophilic groups that are soluble in lipids. They generally fall into three groups, although some surfactants ("amphoteric compounds") can under different conditions act as members of either of the first two groups :

1. Anionic surfactants in which the negative ion is surface-active. These are the most commonly used ; soaps can be classified as anionic surfactants. The most common surfactants were alkyl benzene sulfonates ("A.B.S.") and linear alkyl sulfonates ("L.A S.").
2. Cationic surfactants in which the positive ion is surface-active. These are usually quaternary ammonium salts.
3. Nonionic surfactants in which the whole molecule is surface-active. A popular type is polyoxyethylene nonylphenol.

A wide variety of different surfactants are markted for a wide variety of different solutions, including nonaqueous solutions.

The most commonly used surfactants are compounds known as linear alkyl sulfonates (LAS). An example of a typical member of this group is sodium dodecylbenzenesulfonate.

The A B.S. surfactants show remarkable resistence to biological agents ; for example, perhaps only 30 to 50% of the A.B.S. might biodegrade over a 180-to 200-km trip down a waterway. They could also inhibit the oxidation of certain molecules (such as phenol), perhaps by enveloping them and thus isolating them from dissolved oxygen in the water. They were also noted for interfering

with waste treatment processes by stabilizing small particles in colloidal suspension and reducing the activity of biological filter beds and acivated sludge (but not of sludge digestion). Probably the most notorious effect was their tendency to produce stable foam in rivers, sometimes (especially below weirs and at lockgates) several meters high over an extent of several hundred meters. The problems were so severe that steps were taken to require the use of detergents proved (by specified testing procedures) to be biode gradable.

The beilders added to detergent preparations are generally sodium salts of phosphoric, carbonic, sulphuric, silicic, and boric or similar acids. In their absence, unsequestered hardness ions such as Ca^{2+} and Mg^{2+} can poison the surfactant molecules, preventing detergent action.

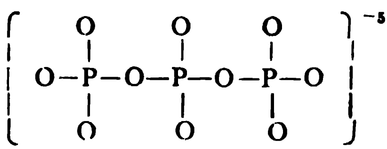
Most laundry detergents contain 35 to 50% of the builder sodium tripolpyhosphate ($Na_5P_3O_{10}$), which leads to the formation of stable soluble complexes [such as Ca $(PO_3)_3^-$] with hardness ions. These phosphates contribute to eutrophication of waterways importance. They might account for perhaps 50% of the phosphates in waste water but a lower fraction of the total phosphates entering waterways from all sources. In recent years the phosphate eutrophication problem has been attackted in two ways : by upgrading sewage treatment facilities to permit removal of phosphates (with 80% removal a common goal) and by outlawing the use of phosphates in detergents, as several countries and some local governmental units in the U.S. have done. Neither of these methods will affect certain phosphorus sources such as runoff from fertilized lands.

A search is presently underway for other builders. For several years there was strong interest in nitrilotriacetate ("NTA"), but it has exhibited a number of undesirable and possibly dangerous properties : hygroscopicity (*i.e.*, it absorbs moisture from the air, which can cause the detergent to cake) ; difficulty in degrading in anaerobic systems such as those found in some septic tanks ; and possible

teratogenic effects (effects that damage the fetus *in utero*) in combination with heavy metals. NTA can also tie up some biologically essential elements and thus harm natural eco-systems. Other builders have shown more difficulties, some being nonbiodegradable. Some products are being marketed with precipitating builders such as carbontes and silicates, which precipitate an insoluble residue with hardness ions but the residue can build up on clothes washing machines. A search is also being carried out for surfactants that do not require builders.

The main role played by the builder in a detergent is that of sequestering agent. These agents tie up hard water ions such as calcium (Ca^{+2}) or magnesium (Mg^{+2}) in the form of large water-soluble ions. In this form, the metal ions cannot interfere with the action of the surfactant. Builders also undergo a reaction (hydrolysis) with wash water which causes the water to become alkaline. This alkalinity is necessary for effective removal of dirt.

The most common builders now used are polyphosphates. An example of a popular one is sodium tripolyphosphate, $Na_5P_3O_{10}$. The active sequestering agent, the tripolyphosphate ion has the structure.



Detergents also contain miscellaneous ingredients such as brighteners, perfumes, anti-redeposition agents and, in some products, enzymes. Brighteners are dyes which absorb invisible ultraviolet light and emit white or blue light. Anti-redeposition agents keep dirt in suspension once it has been removed from a fabric. Carboxymethylcellulose (a product of wood) is commonly used for this purpose.

The surfactant of a detergent acts as a wetting agent. The surface tension of water gets lowered, which permits water more

fully to penetrate the fabric. Also, the surfactant molecules form links between dirt particles and water. This latter activity is possible because of the "bipolar" nature of surfactant molecules. One end is nonpolar and dissolves in the dirt, while the other end is charged and is attracted to and dissolved in water.

The growth in popularity of detergents during the past 20 years has been dramatic. Much of this popularity has been a result of their superior cleaning efficiency, particularly when used in hard water or under other unfavorable conditions.

How do surfactants get into the water supply ? They enter the ground from cesspools, sewage plant outlets, and waste water spreading beds and will readily percolate into the underground water supply. If water wells are in the vicinity or within range of the underground flow, the water that is pumped from the wells will be contaminated with surfactant.

When foaming of domestic and irrigation well water was first noticed, the most commonly used surfactant in detergents was ABS, an abbreviation of *alkyl benzene sulfonate*. ABS was cheap and effective, but highly resistant to microbial degradation. Foaming caused by ABS was severe in some irrigation waters and in lakes and streams used as recipients for municipal and industrial effluent. Extreme foaming occurred in many municipal sewage plants where foam was blown about by the wind, causing a nuisance and unsanitary conditions in surrounding neighborhoods.

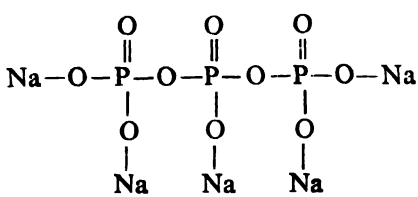
A completely suitable detergent for household use would have to be inexpensive, safe (especially since 2000 to 3000 children swallow cleaning products annually, and not environmentally troublesome, in addition to doing a good job of washing. Some products advertised in recent years as being low-or no-phosphate have made use of caustic chemicals capable of producing eye and skin irritation or illness among children who accidentally ingest them. Other products of the market appear satisfactory in all regards, even though they may not provide the "whiteness" so highly advertised by the leading detergent manufacturers.

About 25 billion pounds of detergents are used annually. Most of it is flushed into the sewer systems from bathrooms, kitchens, laundries, factories, and other industrial establishments.

Detergents that contain water softeners do a better job of cleaning. They help reduce bacteria and other microbes and materially contribute to minimizing cross-infection. If water softeners were eliminated from detergents and not replaced with other conditioners, cleanliness in the home would be reduced. Automatic dishwashers would clean so poorly that they would be almost useless. There would be serious impairment of sanitation in schools, restaurants, hotels, and hospitals. Food-processing industries such as dairies, poultry farms, meat-packing houses, and canneries would be required to modify their cleaning practices or else suffer from lowered sanitation standards.

Phosphate Action

The major components of synthetic detergents, known in the trade as "syndets," have been one or more inorganic phosphate compounds that have been added to make the products resist hard water and clean more efficiently. Syndets contain anywhere from less than 1 per cent to more than 70 percent phosphate. The actual phosphorus content of most household laundry detergents formerly averaged between 10 and 12½ per cent, but the amount used has been steadily decreasing as substitute preparations are placed on the market. Sodium tripolyphosphate, the most widely used phosphate "builder" in detergents, is one of a family of phosphates used extensively as water softeners.



sodium tripolyphosphate

The value of the polyphosphates is in their ability to form soluble complexes with alkaline earth metal ions, mainly calcium and

magnesium ions found in hard waters. Compounds having this action are called *sequestering agents.* The calcium ions in water is captured by *coordination sites* within the molecule of the tripolyphosphate. In the absence of water softeners, the metal ions react with soap and other surface-active cleaning agents with the formation of insoluble precipitates. These precipitates are responsible for the "curds" formed in hard water. They aggravate the "ring" of dirt that forms in the bathtub.

Another property of the polyphosphates has been the ability to break up curdlike particles, an action called *deflocculation,* and to hold the water-insoluble materials in the form of a *colloidal* suspension. Colloidal particles are those that are suspended in very finely divided form and often form extremely stable suspensions.

Pollution Problems Involving Detergents

Water pollution problems resulting from the use of detergents involve either the surfactant or the builder. Problems involving the surfactant were the first observed, and they have largely been solved.

Surfactants in use now have been similar but not identical to those used ten years ago. The main difference has been that those now in use are *biodegradable,* or readily broken down into simpler compounds by bacteria present in the environment. The nonbiodegradable types used prior to 1965 resisted bacterial action, passed through sewage treatment plants essentially unchanged, and persisted in water for long periods of time. Eventually they get decomposed, so the difference between the two has been mainly the rate of decomposition.

Following World War II, detergent use increased and it slowly became evident that the detergents were persisting in the environment. The evidence was not toxic water, but foam. Waste water commonly carried a huge cap of suds in areas of heavy detergent use. The foam distressed people because it was visible and esthetically unacceptable. Drinking water with a "head" on it just never caught on.

It was discovered that the surfactants used were not being degraded rapidly, which led to their buildup in waste and re-used water. The problem was solved by chemically altering the molecular structure of the compounds, making them more tantalizing to the bacteria. The change from nonbiodegradable to biodegradable surfactants was made in 1965 and apparently solved the problem.

The main builder used in detergents is $Na_5P_3O_{10}$. This material presents no biodegradability problems because the $P_3O_{10}^{-5}$ ion undergoes a slow hydrolysis reaction in the environment to produce orthophosphates that are completely nontoxic. The reaction is :

$$P_3O_{10}^{-5}-2H_2O \rightleftharpoons 2HPO_4^{-2}+H_2PO_4^{-}$$

Polyphosphate builders are of great concern because they and their hydrolysis products obviously contain phosphorus, which has been implicated in the eutrophication process.

In 1945, when detergent use began to increase, the potential fertilizing effect of the phosphorus included in the formulation was probably not considered important, if it was considered at all. Today it has been recognized that the widespread acceptance and use of detergents places quantities of phosphorus compounds which are not negligible in waste water, and they must be considered.

It is generally accepted that detergent use accounts for about 50% of the phosphate in waste water : near large metropolitan areas where there has been little dilution of waste waters, some estimates make detergents responsible for up to 70%.

Detergents have been named as the principal contributor of phosphorus to surface waters afflicted with man-made eutrophication. According to a 1970 congressional report, detergents were the largest single source of phosphorus pollution in Lake Erie and Lake Ontario. It was estimated that detergents accounted for more phosphorus in Lake Erie than all other sources combined. Seventy per cent of the phosphorus contributed to Lake Erie came from municipal and industrial wastes, and about 50 to 70 per cent of the phosphorus content of these wastes was from detergents.

Phosphates are not necessarily contaminants. Phosphates are widely recognized and needed as valuable fertilizers in agriculture and horticulture. They are important, therefore, in human food production as well as in plant and animal nutrition. Phosphates also have a wide variety of domestic and industrial uses. It is only when phosphates accumulate in excessive concentrations in surface waters that they become pollutants. Even then, high concentrations will not cause trouble if one or more of the other nutrients are inadequate for the development of phytoplankton. Too often, however, our penchant for perfection has the unintentional effect of setting the stage for eutrophication : enrichment of the water with nutrients, accelerated growth of algae, oxygen depletion of the surface water, and impaired fish production. The ecological balance gets destroyed.

Because of a rapid increase in eutropoication of natural waters various proposals have been made to limit the use of phosphates in or to completely remove them from detergents. Their removal from detergents has proved to be a matter of some controversy, since it is not known for sure that lowering phosphate levels in natural waters will indeed slow down the eutrophication process.

In spite of the fact that there has been a great deal of conflict in scientific opinions and no proof that elimination of phosphates from laundry products will help the eutrophication problem, detergent manufacturers are taking steps to reduce the amount or to eliminate phosphates entirely from their products.

PHOSPHATE REMOVAL

Methods for removing phosphates from sewage are being studied in an effort to devise procedures that would be both effective and economical. The removal of the phosphates from detergents would eliminate about 280 million pounds of phosphorus per year from surface waters, but at least 680 million pounds from other sources would remain. Even if all man-made sources were eliminated, at least 250 million pounds of phosphorus would be deposited in surface waters from natural sources.

As much as 90 to 95 per cent of the phosphates can be removed from municipal sewage with present technology. Procedures that presently appear to offer the greatest promise involve chemical treatment of the waste water. One method consists of treatment with lime and the removal of the phosphorus as insoluble calcium phosphate. Another method brings about coagulation by treatment with an alum. A chemical-biological process involves chemical treatment at the primary sedimentation stage. Other processes and refinements to improve efficiency and reduce costs are now being developed.

The most desirable procedure would be to eliminate phosphates at their source. However, if using substitutes in detergents were to add several cents a box to the cost, the added premium might exceed the expense of removing algal nutrients from wastes.

It is not always possible to predict that reducing phosphorus or nitrogen will result in a proportional decrease in algal growth.

Nonphosphate Detergent Formulations

Two interesting questions are raised by this action :

1. What alternatives to phosphates exist for detergent formulations, and what problems, if any, are created by these new formulations ?
2. What effects will the removal of phosphates from detergents actually have on the environmental problems of eutrophication and lake aging ?

An obvious alternative to phosphate-containing detergents has been soap. Soap was an acceptable cleaning agent before detergents ; why not now ? Two good reasons for not returning to soap are :

1. The supplies of fats and oils are inadequate to furnish the raw materials for the quantities of soap that would be needed. If soap were used to replace the current annual production of 5 billion pounds of detergent, about 2.3 billion pounds of tallow would be required. The use of

this much tallow would put soap makers into competition for tallow that now goes into world food supplies.

2. The performance of soap is markedly poorer than detergents. These machines were specifically designed to use detergents. Soap is totally unsuitable for use in automatic dishwashers.

Detergent manufacturers are trying to eliminate phosphates from detergents and are approaching the problem from two directions. A builder is being sought with properties similar to phosphates. An alternate solution would be the discovery of good surfactants that will work without a sequestering-type builder.

Literally thousands of compounds have been screened and tested as possible partial or full replacements for phosphate builders. A replacement has been difficult to find because of the desirable qualities possessed by phosphates.

1. Phosphates have been nontoxic to aquatic life and pose no health hazard to man.
2. Phosphates have been safe to use on colors, fibres, and fabrics of all types. This is especially important today with the availability and use of so many synthetics.
3. Phosphates have been safe for use in washing machines, being noncorrosive and nonflammable.

Phosphates have other good points when looked at from the standpoint of water quality.

1. They break down satisfactorily, through hydrolysis, in sewage treatment plants and surface water. After breaking down, they no longer behave as sequestering agents.
2. They do not interfere with other waste treatment procedures.
3. They could be effectively removed from waste water in treatment plants.

4. Their chemical structure and reactions are already well known, having been investigated and documented for many years.

Phosphates have been the most economical materials available for softening water and improving the efficiency of cleansing agents. But phosphates are not the only substances that can do the job. There are a large number of materials that resemble the polyphosphates in their ability to form soluble complexes with metals, including the main culprits in hard water, calcium and magnesium. Such materials have been used for many years for a wide variety of applications. They are called *chelating* agents, from the Greek word *chela*, meaning "claw." Many of the chelating agents are synthetic amino acids. One of the simplest and cheapest is nitrilotriacetic acid, or NTA.

NTA has been found to be effective as a water softener, to aid in the dispersion of dirt, to help maintain the proper alkalinity of the water, and to aid the surfactant in loosening the dirt. NTA was also found to be 70 per cent degradable during the biological activity phase of sewage treatment. The water-softening action of NTA resembles that of the tripolyphosphate. A calcium or other metal ion is captured (chelated) in a network of bonds where it is held so tightly that it cannot cause trouble.

Prior to its use, extensive human and environmental safety testing indicated that at the levels used currently and contemplated for the near future, NTA was safe. Normally, NTA has been degraded in waste treatment systems and in the environment. In the degraded state, it loses all ability to combine with metals. It does not, however, degrade under anaerobic conditions such as may be found in some septic tanks. This raised the possibility that such nondegraded NTA might react with heavy metals known to be present in water.

This situation reveals the great care that has to be taken to insure that alternatives to phosphate do not present equal to greater

hazards to the environment. One big concern relative to phosphate replacements has been that their chemistry and behavior in the environment will not be known and will have to be obtained over long periods of time by careful observation and experience.

Early experiments with animals gave no evidence of high acute toxicity from NTA, and there had been no indication of genetic effects. However, new information from toxicological studies became available shortly after producers of NTA had expanded production capacity and the major detergent manufacturers had changed their formulations to contain the chelating agent. Experiments or rats and mice with NTA in combination with cadmium or methyl mercury showed an increase in congenital abnormalities as compared to the same dosages of metals when administered alone. NTA triggered a tenfold increase in fetal abnormalities and fatalities.

There were other objections. NTA is believed to be converted mainly to nitrite and nitrate, which are toxicants under some circumstances and also furnish nutrients to microorganisms and higher plants. Replacement of one nutrient for another is of questionable value. But a more serious possibility is the metabolic formation of *nitrosamines*, a group of compounds which includes some highly carcinogenic (cancer-causing) substances. NTA was removed from the market pending further investigations of its biological effects.

Several other materials can be used in place of phosphates as detergent "builders." Sodium carbonate, known also as *soda ash*, is a mildly alkaline material commonly added to detergent formulas, but it can be injurious when ingested, especially by children. One of the borates known as *borax* is widely used as a cleansing agent. But sensitive trees and shrubs have been damaged by waste water from industrial cleaning operations in which borates were used.

One substitute for phosphates is a material called *sodium metasilicate*. The silicates are effective water softeners, but they have a major drawback. They are strongly alkaline materials which irritate the skin and eyes. Sodium metasilicate was fatal to laboratory rats when fed to them in small quantities.

These builders are having some disadvantages. The buildup of calcium and magnesium salt residues is one. These solids can become deposited in the articles to be washed, with the result that the wash looks "dull". Sequestering builders keep the metals in solution as large ions and avoid this problem. The precipitating builders give much more alkalinity to the wash water than do phosphates. Phosphate detergents produce wash water with a *p*H of 9 10.5. The nonphosphate detergents usually result in wash water with a *p*H of 10.5-11. A solution with a *p*H of 11 and above is approaching a value where skin corrosion, serious eye irritation, and ingested toxicity become problems. At these high *p*H values the solutions apparently form gels with protein tissues and become very difficult to remove before serious damage has been done. The FDA ts beginning to screen nonphosphate detergents for such excessive *p*H problems.

Research is in progress following both approaches to the problem despite the fact that nearly everyone agrees that reformulation of detergents has been really a short-range objective. The best long-range method for controlling all plant nutrients, including phosphates, is advanced sewage treatment systems. Phosphates can now be removed by such treatment, and methods are being developed to remove other plant nutrients.

Detergent reformulation may have to suffice for a while due to the time lag in getting public financing for comprehensive treatment systems. Clothes might not be whiter than white in the near future, but simply clean.

Effects of Phosphate Removal on the Environment

After all previous information of this chapter has been weighed, one question still remains : will the removal of phosphates from detergents help solve the environmental problem of eutrophication ? The answer, unfortunately, has been not an unqualified yes. In fact, some scientists feel that such removal will have very little effect on the eutrophication problem. In order to illustrate the difficulty involved in making such a decision, some arguments of

those in favor of removing phosphates from detergents and those against such action would be given.

The arguments of both sides have been based on the "limiting reactant" principle, which says that the growth of algae has been limited by the nutrient in shortest supply relative to the amount needed. As soon as this element gets exhausted, growth stops. Research indicates that any of the elements carbon, nitrogen, or phosphorus may be limiting, depending on water conditions.

The arguments against removing phosphates from detergents have been given first since they are in favor of leaving things as they are :

1. Studies in nutrient-rich lakes reveal an excess of phosphorus. This implies phosphorus is not the limiting factor in these instances, although it may be in nutrient-poor lakes.

2. Carbon makes up nearly 50% of the weight of algae. All this carbon gets assimilated through photosynthesis of CO_2. Until recently, few investigators have questioned the sources of this essential nutrient which is needed in huge amounts. Land plants have large leaves in contact with air, their source of CO_2. Water plants must draw most CO_2 from the water, so the amount of dissolved CO_2 may be the limiting factor rather than phosphorus.

3. Phosphates, after once being introduced into a body of water, have been continually recycled in the green plants and algae. When the plants and algae die, the phosphates get released and used again by other plants. This regeneration of phosphorus takes place much more rapidly than that of nitrogen.

4. Large amounts of phosphorus get stored in the bottom muds of lakes in the form of slightly soluble salts of calcium, magnesium and iron. Recent research has shown

this phosphorus to be in equilibrium with dissolved phosphorus compounds. So even if phosphates were removed from incoming water, the bottom muds would provide a supply for many years.

5. Problems could arise involving the substitutes for phosphates if they have been organic sequestering agents. They do not react with water as phosphate does, and so they retain sequestering properties until degraded. Remember the NTA problem. Also, as they presumably will be biodegradable they will require oxygen and increase BOD problems. The degradation products will be compounds of carbon and possibly nitrogen, both of which have been plant nutrients and could cause problems.

The arguments in favor of removing phosphates have been as follows :

1. Even though some water may have phosphorus in excess, the technology for its control has been further advanced than that for either carbon or nitrogen. If phospate were removed it could be made the limiting factor and thus control the growth of algae.

2. The sources of phosphorus have been well known, and they do not get varied as those of carbon or nitrogen. This makes control easier.

3. Carbon and nitrogen have been readily available to aquatic plants from atmospheric sources if they are not present in the water. There is no common atmospheric source for phosphorus. Carbon comes from dissolved CO_2 of the air. Nitrogen is also dissolved in the water from air and then converted to usable forms by certain aquatic plants, including the blue-green algae.

In summary, it is evident that those against removing phosphates from detergents are not convinced that phosphorus has been the limiting factor. Furthermore, they feel that if it is, elimi-

nating it from detergents will not solve the eutrophication problem because a large source of phosphorus is present in the bottom mud. They also seem to feel that in light of the previous two arguments, it has been not worth the risk of introducing new problems in the form of a phosphate substitute.

Those favoring phosphorus removal, on the other hand, feel that because phosphorus has been the most easily controlled of the plant nutrients, it must be eliminated from detergents and made the limiting factor even if it is not the limiting factor at present. They also feel that the storehouse of phosphorus contained in bottom mud must be used up eventually. Why not start using it up immediately? Both sides agree that the best long-range plan has been to treat all waste waters and remove excess plant nutrients.

Some More Detergent Problems

Arsenic

Purified phosphates are among the safest compounds used in consumer products, being incorporated in foods, beverages, and medicines. However, one of the impurities in mineral phosphate deposits, and hence, in commercial phosphate water softeners has been arsenic. This contaminant has been detected at concentrations of 10 to 70 ppm in several commonly marketed household detergents. In view of the fact that much of the sewage is dumped into waterways.

There is danger that arsenic in laundry water may be absorbed through unbroken skin. Skin eruptions and other types of dermatitis allergies have been reported in sensitive people. Baby diaper rash and hand rashes have been associated with arsenic in detergents. When present at 50 ppm, arsenic inhibits the healing of wounds. The accumulation of arsenic in human hair following the use of arsenic-containing detergents was reported as early as 1958. There has been also evidence that arsenic accumulates in the livers of mammals.

Enzymes

Enzyme detergents were introduced in 1968. The enzymes have been intended to attack stains that other detergents cannot remove, especially stains from protein-containing materials : blood, urine, milk, meat juice, and chocolate. The enzymes have been produced by cultures of the microorganism *Bacillus subtilis*, which secretes the enzymes during its digestive process. Unfortunately, the enzyme dusts in manufacturing plants also attack the skin of workers' hands. When inhaled, the enzymes are able to sensitize the lungs, causing allergic reactions resembling hay fever or asthma. The enzymes were found to have several potentially toxic substances that caused disintegration of blood elements and agglutination of red blood cells when injected into the body cavity of mice. Whether or not the smaller concentrations of enzymes to which detergent users are normally exposed comprise a widespread allergic hazard is under intensive investigation. The potential effects of detergent enzymes on aquatic organisms have been also unknown.

People who worked on the foamy-water problem reasoned that if something could be done to make ABS attractive to bacteria, the molecule would be so impaired that its foaming properties would be destroyed. This was accomplished by a modification in the chemical structure of ABS that produced biodegradable detergents called LAS (linear alkylate sulfonates). Why this makes a difference to the microbes no one knows for sure, but it is a happy fact that the microorganisms can easily digest the linear chain and use it as a source of carbon for food. However, phenolic decomposition products of largely unknown biological activity remain. But the foam, odor, and taste formerly imparted to water by ABS have been virtually eliminated.

Chlorination

What may turn out to be the most important finding was the strong evidence that chlorination of drinking water contributes to the formation of some of the contaminants, including the carcinogen chloroform. Purification of domestic water by chlorination has

been not designed to remove chemical contaminants. We do not know whether conventional treatment of sewage effluent leaves most of the toxic components essentially unchanged, degrades and decreases their toxicity, or modifies them in ways that make them more hazardous. The suspicion is growing that the nation's drinking water is not as pure as many people imagine.

Nitrates

The danger of drinking water containing high nitrate content has long been recognized. Livestock have been affected by well waters containing 75 to 150 ppm (parts per million) of nitrate nitrogen. Human infants have been especially susceptible, not only because of their high gastic pH (low acidity) but also due to their high fluid intake relative to body weight. Nitrate poisoning brings about a condition called *methemoglobinemia*, resulting from changes in the hemoglobin of the red blood cells that reduce their capacity to carry oxygen.

Susceptibility of infants to nitrate poisoning has been highest during the first few months of life. Although adults have been not affected by drinking water that is toxic to infants, breast-fed infants of mothers drinking the water may be poisoned because of high nitrate content of the mother's milk. Cow's milk may also have sufficient nitrate to cause poisoning of infants. Nitrate poisoning of infants has been reported from drinking water having nitrate in the range of 15 to 250 ppm of nitrate nitrogen (N), equal to 67 to 1,100 ppm nitrate ion (NO_3^-).

The primary source of excessive nitrates in well water has been the leaching of nitrate salts into the underground water supply from agricultural fertilization and the seepage of sewage.

Poisoning of livestock from feed high in nitrates has been known since the last century. An investigation of deaths in a herd of cattle in Kansas in 1895 established that the poisoning was caused by their feeding on cornstalks having an unusually high concentration of potassium nitrate. The corn had been grown near a barn

on land with an exceptionally high nitrogen content. It was noted that the blood of the poisoned animals was dark in color, but the meaning of this was not understood at the time.

One of the symptoms of nitrate poisoning has been described as *cyanosi*·, in which there has been a bluish discoloration of the skin and mucous membranes. The red blood cells lose their capacity to carry oxygen, causing the blood to turn dark and resulting in death from asphyxiation. The failure of the red blood cells has been due to the conversion of their hemoglobin to a closely related substance, methemoglobin, which cannot combine with oxygen. The conversion is brought about by the action of nitrite on the iron (Fe) in the hemoglobin molecule, which oxidizes it from divalent to trivalent iron. The condition produced by nitrate (or nitrite) poisoning has been termed as *methemoglobinemia*.

$$\underset{\text{can combine with oxygen}}{\text{Hemoglobin } (Fe^{++})} \xrightarrow{\text{nitrite}} \underset{\text{cannot combine with oxygen}}{\text{Methemoglobin } (Fe^{+++})}$$

For a nitrate to be highly toxic it must first get converted to nitrite. In cattle it has been believed to be brought about by action of certain microorganisms prevalent in the rumen, the first pouch of the stomach.

$$\underset{\text{nitrate}}{NO_3^-} \xrightarrow[\text{reduction}]{\text{microbial}} \underset{\text{nitrite}}{NO_2^-}$$

Nitrate poisoning takes place in many animals, including cattle, sheep, horses, turkeys, and man. Cattle are especially susceptible. Nitrate poisoning has been less common and usually less severe in adult humans than in cattle because the conditions in the human adult gut do not favor conversion to nitrite nitrogen from the nitrate form, which readily gets eliminated from the body in the urine. Human infants, however, are highly susceptible to nitrate poisoning. It is believed to get caused by the lower gastric acidity which favors nitrate reduction. The makeup of the intestinal microflora might also be a factor as well as the high carbohydrate

diet of infants which favors the microbial action. A case is on record of two children, two to three years of age, being poisoned from eating wieners containing 5,000 ppm nitrite—an unusually high concentration.

Nitrates have been normally present in many plants, often at levels that cause poisoning of livestock. Plants having 1 per cent nitrates have been toxic to cattle and 0.5 per cent has been to be the maximum that can be tolerated. Excessive fertilization is often the cause of high nitrates in plants. Treatment with hormone-type weedkillers such as 2, 4-D can also cause high nitrate levels.

The amounts of nitrate normally present in vegetables have been not ordinarily dangerous to adult humans. Except under unusual circumstances, large amounts could be tolerated without adverse effects. However, if for some reason the nitrate is reduced to nitrite during storage of the food, the nitrite may reach levels that are poisonous to infants. Most of the reported cases get resulted from spinach purees in which the conversion may have taken place in frozen products. However, leafy vegetables are often fertilized heavily during growing and may contain high concentrations of nitrates initially.

The blood of heavy smokers is having as much as 7 to 10 per cent of the hemoglobin converted to carboxy-hemoglobin because of habitual inhalation of carbon monoxide. Carboxyhemoglobin is also not capable of transporting oxygen, so the effects of nitrite poisoning and carbon monoxide poisoning have been at least additive. The high concentrations of carbon monoxide in the atmosphere of urban and industrialized areas adds appreciably to the burden of the oxygen-carrying function of the blood. There has been also some nitric acid in the air from urban pollution, and nitrate salts are present in aerosol form. The contribution to nitrate poisoning has been probably minor, but when added to the rest of the burden, may be significant.

The effect of nitrates on the human fetus has not been fully studied. When pregnant cattle graze on land where the plants has

been high in nitrates, they may abort without showing any of the acute symptoms of poisoning. Abortion can be expected in pregnant animals that survive prolonged and severe poisoning. When fetuses get aborted in the absence of acute poisoning symptoms in the mother, lesions that would be expected from prolonged hypoxia (oxygen starvation) are found in the fetus. Microscopic examinations show thickening and blocking of the arterioles. More information is required on the sensitivity of fetal and infant hemoglobin to the action of methemoglobin-forming agents.

A relatively recent cause for concern has been the potential cellular toxic effect of nitrates and nitrites. Substances that adversely affect cells are said to by *cytotoxic.* Nitrous acid, which contains nitrite nitrogen, has been known to be mutagenic since 1953. Its action is believed to be through the formation of nitrosamines.

OIL

Introduction

During recent years the public has become increasingly aware of the presence of oil pollutants in the sea. Photographs and descriptions of oil-soaked birds floundering on oil-covered beaches have become almost routine presentations of the visual news media.

Oil pollution has been an almost inevitable consequence of the dependence of a rapidly growing population on oil-based technology. The use of natural resources such as oil on a grand scale, without losses, has been almost impossible. The extent of such losses, intentional or accidental, has been steadily increasing and has been becoming a great cause for concern.

It has been estimated that the total oil influx into the ocean has between 5—10 million tons annually. The major sources are :

1. *Cargo tanker washings at sea.* The widespread practice of using sea water as ballast for empty tankers contributes an estimated 3 million tons of oil to the oceans annually. This occurs when the ballast gets dumped and carries residual oil from the tanker into the sea.

2. *Bilge pumping at sea.* The dumping of bilge contents by ships other than tankers contributes an estimated 500,000 tons per year.

3. *In-port oil losses.* These losses take place during loading and unloading procedures and also as a result of collisions in port. The estimated annual contribution to oil pollution of the sea has been 1 million tons.

4. *Other sources.* Some other sources are not easily assessed but do contribute to the problem. Vessel accidents on the high seas or near shore certainly add to the problem and receive great amounts of publicity. The largest spill to date in this category occurred when the tanker *Torrey Canyon* ran aground off the coast of England in March of 1967. The oil spill amounted to 100,000 tons.

Losses also take place during exploration for and production of oil. The blowout of wells, disposal of drilling muds and other wastes, and accidental damage to offshore drilling rigs all constitute significant potential pollution sources. In this case, the flow of oil continued unabated for eleven days despite efforts at containment.

Oil leakage from the 200,000 miles of pipeline that crosses waterways and reservoirs has been a possible source of polluting oil. These lines have been subject to cracks, punctures, corrosion, and other sources of damage which would lead to leaks.

It is estimated that nearly 2 million tons of used lubricating oil is unaccounted for each year. It has been assumed that much of this eventually reaches coastal waters.

The Fate of Spilled Oil

Oil and water don't mix : so we have been told. According to this old adage, it might be expected that spilled oil would just float around until it got washed ashore. This, however, is not the case. One gallon of oil will cover an area of four acres of water when completely spread out. During the time it has been spreading, many changes take place in the oil. All oils, regardless of type,

have volatile components that evaporate readily. Within a few days 25% of the volume of a typical oil spill is lost through evaporation. The remaining oil has been subjected to emulsification processes which, in a sense, do cause oil and water to mix.

Two types of emulsions have been formed. Oil-in-water emulsions result when small droplets of oil get dispersed in water and are stabilized by chemical interaction with the water at their surfaces. This process occurs especially well in turbulent seas. The resulting oil droplets do not get dispersed on top of the water, but rather throughout the water. Some oil droplets, especially those weighted down by mineral particles, even reach the bottom.

Water-in-oil emulsions form when water droplets get enclosed in sheaths of oil. The emulsion gets stabilized by interactions between the enclosed water droplets and various resinous and asphaltic materials found in most crude oil. This type of emulsion shows up as a floating, sticky, viscous mass that, on occasion, contains enough water to cause the total volume to be greater than that of the original oil.

Most oil that survives the emulsification processes gets degraded by spontaneous photo-oxidation and oxidation by microorganisms. The microorganisms have been the most powerful source of oil decomposition found in the sea.

By the end of three months at sea only about 15% of the original volume of an oil spill remains. This is in the form of black, tarry lumps of a dense asphaltic substance, and it has been these lumps that frequently wash up on beaches.

When massive spills take place close to shore, sufficient time has been not available for the process described above to affect the total amount of oil involved. Under such circumstances a thick sticky film of oil gets deposited on any solid that comes in contact with the spill.

Biological and Physical Effects

The problem of oil pollution may be thought of in terms of short-term and long-term effects. The short-term effects have been

immediately obvious and have been the ones that have received the most publicity. The long-term effects have been only slowly becoming apparent and have been currently the subject of much study.

Short-term effects fall into two categories, those caused by coating and asphyxiation, and those that result from oil's toxicity. The effects caused by coating and asphyxiation are :

1. *Reduction of light transmission.* Measurements have regarded that ambient light intensity 2 metres below an oil slick was 90% lower than at the same depth in clear water. Photosynthesis by marine plant life may get hampered by extended periods of such conditions.

2. *Dissolved oxygen reduction.* Oil films are able to retard the rate of oxygen uptake by water. Measurements have shown a significantly lower dissolved oxygen level in water beneath a slick than in clear water. The final effects of this could not be determined.

3. *Damage to water birds.* Swimming and diving birds get covered with oil. This causes their feathers to mat together, reducing their buoyancy and preventing flight. The insulative value of the feathers has been also lost, and some birds quickly die of exposure in cold water. It has been estimated that 25,000 sea birds died because of the *Torrey Canyon* incident.

4. *Smothering.* The effects of oil on plant life along shorelines are becoming a matter of concern. Intertidal algae and lichens are known to have been killed by smothering coats of oil which washed ashore in some areas.

The toxic effects of oil get resulted from some of the many compounds that make up this very complex mixture. These compounds have been found to vary widely in their molecular weights and structures.

Until recently, low-boiling saturated hydrocarbons were regarded to be harmless to a marine environment. It has now been demonstrated that these substances, in low, water concentrations, cause anaesthesia and narcosis in a wide variety of lower animals.

Cell damage and death result in animals exposed to high concentrations. It has been indicated that larvae and other young forms of marine life may get especially affected.

Low-boiling aromatic hydrocarbons have been abundant in oil and represent its most dangerous fraction. Such compounds as benzene, toluene, and xylene have occurred in this fraction. These substances have been acute poisons for man as well as for all other living things. Naphthalene and phenanthrene, also present in oil, have been even more toxic to fish than the three compounds mentioned.

The aromatic compounds have been more water-soluble than the saturated hydrocarbons. The aromatics are able to kill marine organisms by direct contact (with oil) or through contact with dilute solutions created when the compounds dissolve into the water from the oil. The effect of these compounds diminishes somewhat with time because they have been volatile components of oil and evaporate.

Observations conducted on oil spills close to shore reveal that massive, immediate destruction of marine life takes place during the first few days after a spill. The species affected include a wide range of fish, shellfish, worms, crabs, and other invertebrates. Bottom-living fish and lobsters get killed and washed ashore. The toxicity has been immediate and causes death within minutes or hours after contact.

The long-term and especially low-concentration effects of oil components on living systems have been not as apparent as short-term effects. Some possible areas of concern have been proposed and are being studied.

Many biological processes of importance to the survival of marine life and occupying key positions in their life processes have been mediated by extremely low concentrations of chemical messengers in sea water. Marine predators, for example, have been attracted to their prey by organic compounds present in the sea water at concentrations in the ppb range. Similar chemical attractions and

repulsions play vital roles in such processes as finding food, escaping from predators, locating habitats, and sexual attraction.

There is reason to believe that some compounds of polluting oil have been found to interfere with these processes by blocking the taste receptors of organisms or by mimicking the natural stimuli, which gives rise to false responses on the part of the organisms. High-boiling saturated and aromatic compounds have been the ones likely to interfere in this way. Such interference could be having disastrous effects on the survival of some marine species.

The fate of organic compounds which enter the marine food chain has been studied. Results indicate that hydrocarbons, once incorporated into a particular organism, have been quite stable, regardless of their structure. There has been also evidence that these compounds can pass through many members of the marine food chain without becoming altered. Such compounds have been thus subject to food-chain amplification analogous to the situation found for heavy metals and pesticides.

The food chain eventually reaches marine organisms that have been harvested for human consumption. This presents the possibility that the flavor of sea-food might be negatively affected, or, much worse still, that potential long-term poisons might accumulate in food used for human consumption. This latter point has been especially unnerving when it has been regarded that some of the high-boiling aromatic hydrocarbons involved have been known or thought to be carcinogenic.

The food-chain amplification could also give rise to situations in which marine life high on the chain would accumulate quantities of the compounds sufficient to destroy them.

Emulsified oil may reach the sea bottom, as mentioned before, especially if it is weighted down by mineral particles. Oil on the sea floor usually persists for long periods of time and can continue to damage bottom plants and animals. The destruction of these plants and animals is able to reduce the cohesion of bottom sediments and

accelerates their transport. Sediment movement has been commonly observed following oil spills. Contaminated sediments can be spread over great distances under the influence of tide and wave action.

Recent reports have posed an additional environmental threat from oil pollution : the oil may serve as a concentration medium for other fat-soluble poisons such as pesticides. Dissolved in an oil film, these poisons might reach concentrations many times higher than those common in polluted water. These poisons could, in this way, reach susceptible organisms in concentrations much higher than they would normally encounter.

Countermeasures for Oil Pollution

The obvious solution to this problem has been to prevent it from happening. As the principal cause of oil spills has been human error, much effort can and should be directed at prevention. An area where progress can be made in this direction is transportation, where improved navigational aids (both ship-and shore-based) and improved safety and hazard warning instrumentation could prove effective. Off-shore drilling operations require improvement. Some suggestions have been the development of submerged pyramid-shaped canopies to cover the drill hole area and collect and trap any spills, the use of mechanical or pneumatic (air curtain) walls around the drill site, and the use of some form of physical encapsulation of the drill and drill hole.

Accidents will occur in spite of prevention methods, and preparations must be made to handle such events. This is especially crucial because accidents often cause in massive amounts of oil being released into small areas. The areas of immediate concern in the event of a massive spill have been containment of as much oil as possible at the scene of the spill, and countermeasures for any oil that escapes containment. At the present time, neither area has been without numerous problems.

Some proposals for research into at-source prevention have been made. These have been as follows :

1. Development of techniques to instantaneously convert the contents of storage or transport tanks into a gelled and viscous material that will not easily flow through ruptured tank walls of which might form self-sealing plugs.
2. Development of new methods for quickly patching holes in tankers, pipelines, and so forth.
3. Development of improved and accelerated salvage techniques.
4. Development of rapid, mobile, off-loading techniques coupled with transportable (possibly inflatable) containers, all of which could be air-lifted to accident sites.

Until progress could be made in the areas of at-source prevention, other containment and countermeasures will have to be used. Improvement is needed in these areas as well since, problems do exist with the present methods.

The containment of an oil spill of necessity has been involving the creation of some sort of barriers. Three types of barriers are used or are in the developmental stage. They have been floating booms, water bubble barriers, and chemical barriers.

Floating booms have been in common use in harbors and areas where the transfer of petroleum products occur. These booms have been constructed of a tubular floating section, which is inflatable or is filled with some buoyant material. Some sort of weighted skirt is generally suspended below the floating section. These booms are used to encircle and contain spills until they can be removed.

The success of these devices has been found to depend upon the conditions under which they get used. They are most effective in calm water and when used on small spills. Most commercially available models have been unsatisfactory in the open sea or in any rough water because they become difficult to anchor, and wave action carries the oil over and under the barrier. Larger, more bulky and more rigid booms overcome this problem, but they have been more difficult to transport and set up.

In emergencies, makeshift booms have been used. Construction materials for these devices include inflated fire hose. linked railroad ties, and telephone poles. A considerable amount of development and improvement has been necessary to make floating booms useful in the rough-water situations that often accompany (and sometimes cause) accidental spills at sea or in harbors.

Water bubble barriers could be formed by releasing compressed air from a perforated, submerged piece of tubing. The air rises to the surface as a curtain of tiny bubbles. The resulting agitation disallows or at least inhibits the movement of oil films across the curtain. The barrier works as long as water current and wind do not overcome the forces set up by the compressed air. These barriers have been quite new and, although totally impractical for the open sea, they are in use in some harbors. One distinct advantage has been that they do not impede the movement of vessels.

Certain chemical additives have been capable of gelling or even solidifying oil. If these could be applied effectively to the periphery of an oil slick, it has been conceivable that a ring of gelled oil could serve as a containment barrier, possibly in very rough seas. Work along this line has been still in the experimental and development phase.

The job of containment has been much easier in harbors and protected waters than on the open sea, where high waves and anchoring still does not allow effective use of barriers.

Whether or not containment of a spill has beed successful, the task of cleanup and removal must get accomplished. The rash of spills in recent years has allowed numerous cleanup methods to be tried with the hope of finding a "best" one. Apparently some methods have been better than others, and, in fact, some should be avoided completely because of long-term effects. Indeed, some of the more obvious methods have been among the least desirable.

Mechanical methods of cleanup have been very satisfactory from two points of view. The oil has been removed from the water and reclaimed for productive use. Mechanical removal involves the

use of skimmers, which get attached to ships and which effectively skim the oil and a thin layer of water from the surface. The oil and water are allowed to separate in storage tanks within the ship, and the water is then pumped out.

All skimmers now in use work best in calm waters and on thick layers of oil. They are quite effective on oil slicks contained by floating booms. The present recovery rate of skimmers has been between 10 and 50 barrels per hour, depending on the calmness of the water and the type of skimmer. In summary, skimming has been an ideal method for use on small, contained spills, but it has been beset with difficulties when used on large spills in open water.

Hydrocarbons have been naturally degraded by marine microorganisms. Accelerated biological degradation, using these same microorganisms, could be applicable to those oil spills in the open sea which will not reach shore for several days. This technique would be involving bacterial seeding and fertilization of the oil slicks. In order to assure complete degradation, sufficient time would be required and all appropriate bacterial species would have to be used. These bacteria are highly selective, and no single species could degrade all components of the oil.

A number of problems have been found to accompany this technique. The main one has been the severe oxygen requirement for the degradation process. The complete degradation of 1 gallon of crude oil requires all the dissolved oxygen in 320,000 gallons of air-saturated sea water. Therefore, the oxidation will be slow (and may be the slick will reach shore) in areas where the oxygen content of the water has been low (possibly from previous pollution). The degradation might bring about additional damage to marine life by depleting the oxygen.

Combustion was one of the earliest methods used to rid water of oil pollution. It has been an attractive and inexpensive method for disposing of large amounts of oil. It has been, of course, inadvisable in situations where the oil has been close to shore or to structures that could be damaged.

Generally, burning has been effective only if it can begin immediately after a spill. The lighter fractions of oil evaporate immediately after a spill, and the remaining oil is having a higher ignition temperature and can be difficult to ignite. This factor, coupled with the ability of water to conduct heat away from the burning oil, has caused some attempts to be unsuccessful. Research has been now aimed at developing "aids to combustion" in the form of wicks, catalysts, and supplementary fuels. Further developments in burning techniques may give rise to methods very useful on large spills in the open sea. One drawback has been that water pollution has been converted to air pollution, since dense black smoke is generated. The residue after burning has been a black solid that has been easier to collect than the liquid oil.

Small amounts of oil could be removed by sorbents. Oil gets soaked up by an absorbent and clings to the surface of particles of an adsorbent. Either type of sorbent could be used to remove oil from the surface of water. The use of such materials is having the advantage of limiting the rate of slick spreading and facilitating cleanup. The disadvantages include problems of delivery and application of the materials, and collection and disposal of the oil-soaked products. Also, the method is prohibitive with extremely large slicks due to the amounts of materials involved.

Straw and sawdust are used as sorbents. After becoming saturated with oil, they might be removed and disposed of. Shredded polyurethane foam, an absorbent, is used and has the advantage that, when it gets saturated, it can be removed and the oil can be squeezed out. The foam can then be reused. The recovered liquid is 80% oil, which can be recovered for use. A volume of 50 ft^3 of foam will reportedly soak up 1 ton of crude oil.

Sinking agents, in the form of sand, brickdust, cement, silicone mixtures, and fly ash, are added to oil spills. The combination of oil and sinking agent has been heavier than water, and the oil sinks. Some of the agents have been chemically treated to increase their properties of being attracted to oil and rejected by water. In order to be most effective, the sinking agent should not release the oil back

to the water environment. This has been a problem with some agents.

The French used large amounts of sinking agents on the oil slick from the *Torrey Canyon* incident. It removed the immediate problem of having the slick reach the shorelines.

It now appears, because of studies on long-term effects, such as those previously discussed that physical sinking has been one of the least desirable methods of treating oil spills. Sunken oil kills bottom-dwelling animals so rapidly that most mobile dwellers have insufficient time to move. Oysters, scallops, and lobsters have been among the species affected. The oil may form a layer or "blanket" on the bottom and persist for long periods of time.

The bacterial degradation of sunken oil needs large amounts of oxygen. Because of this sediments loaded with oil may become anaerobic. One of the principles of geochemistry has been that hydrocarbons in anaerobic sediments persist indefinitely. Anaerobic sediments have been very slowly reworked and repopulated, so such sites might constitute sources of water pollution for a long time after the original spill.

Many materials have been available that will be able to emulsify oil in water. These products are known by a variety of names, such as emulsifiers, detergents, degreasers, and dispersants. We shall employ the term *dispersant*. The primary components of a dispersant have been a surfactant, a solvent, and stabilizers. The surfactant has an affinity for both oil and water and allows the two to mix. Solvents enable the surfactant to penetrate into the oil slick. The solvent usually makes up the bulk of the dispersant composition. Stabilizers are able to fix the emulsion once it is formed. The net effect of the dispersant has been to lower the surface tension of the oil to the point where it will break up and disperse in the water in the form of tiny droplets.

The action of dispersants is able to increase the surface area of an oil slick and distributes the oi! droplets into a large volume of

water. These two effects are able to enhance the natural degradation by microorganisms. The chemical dispersants themselves are not able to destroy any oil.

Dispersants have been usually applied by spraying. Agitation becomes necessary to make them effective. This makes them very useful on oil slicks in rough open sea where nature does the agitating. Evaluation of the results of their use in the past reveals that dispersants must be used with caution. The high degree of dispersion they create leads to greater solubility and higher concentrations of oil in the water than would be possible if natural dispersion were allowed to take place. Also, the oil droplets formed have been in a size range that has been easily ingested and assimilated by marine organisms on the low end of the marine food chain. In the case of the *Torrey Canyon* incident, some of the dispersants used were found to be as toxic to aquatic life as the oil itself.

Dispersants used on beaches actually add to the problem by making the oil to penetrate more deeply into the sand. The compactness of the sand has been upset, and it becomes more easily moved by tide and wave action. This contributes to beach erosion.

PESTICIDES

Introduction

Pesticides are one of a large group of chemicals used to kill or to control the growth of plants and animals considered by a user of the chemicol to be a pest. Chemicals used primarily against infectious becteria causing human, animal, or plant diseases, as well as those employed in the treatment of viruses, protozoas and internal parasites of animals, plants and humans, have been usually not classified as pesticides. Also somewhat arbitrarily excluded from the pesticide group are chemicals designed to combat marine fouling organisms. The principal families of pesticides are listed in Table 10.5. Pesticides, of course, are widely used against insects, acarids, and various rodents that transmit disease-causing microorganisms to humans.

Table 10.5. Classes of Pesticides

Class	*Purpose*
Acaricide	Used against mites and ticks, members of the Acaridae
Algaecide	Used against algae
Antifouling agent	A paint additive to protect against organisms that grow on moist or wet surfaces including those underwater
Attractant	A chemical that attracts insects or birds or other animal pests to a trap or a poison
Avicide	Kills or discourages birds
Chemosterilant	A chemical that will lower or stop reproduction by a pest
Defoliant	A chemical that induces plants to drop their leaves prior to harvest (sometimes used as a herbicide or silvicide)
Desiccant	A chemical that dries plants out before harvest
Fumigant	Used to kill soil pests and sometimes weeds
Fungicide	Used against fungi
Herbicide	A weedkiller, strictly speaking, but defolints and silvicides are often called herbicides
Insecticide	Used against insects
Miticide	(See Acaricide)
Molluscide	Used to kill or control mollusks and other invertebrates (*e.g.*, predatory snails, sluge, oyster drill, lamprey)
Nematicide	Used against nematodes, tiny round worms that feed on decaying matter, roots, or other parts of plants
Ovicide	A chemical used against the eggs of insects, mites, and nematodes
Piscicide	Used to reduce the population of rough fish in a body of water
Plant regulator	A chemical that alters the normal pattern of growth and development of a plant ; usually used for herbicidal purpose
Repellent	A chemical that repels insects or other animals
Rodenticide	Used against mice, rats, and other rodents
Silvicide	Used against brush, trees and other woody plants and shrubs (often lumped with the herbicides).

Man finds it necessary to do battle with natural "pests," including insects, because they are able to compete with him for his means of survival. When pests threaten, man tries to find a means for destroying them.

According to the latest estimates, 3 million different species of insects are now in existence. This is far more than the number of all other animal and plant species combined. The number of individual insects alive at any one time is thought to be about 1 billion, billion (10^{18}). Of this vast number, 99.9% are, from the human point of view, either harmless or, in fact, helpful. A few, such as pollen-transferring bees, are considered indispensible. The troublesome species comprise 0.1% of the total, or about 3000 species. Most of these are agricultural pests or carriers of human and animal diseases.

If man is to have food, remain relatively disease-free, and prosper, the freedom of these selected few insects to pursue their natural activities must be destroyed. At our present stage of technological development, synthetic organic chemical insecticides are the most significant means of accomplishing this task.

These insecticides have come under intense scrutiny because of the increasing attention given to the relationships between man-made chemicals and the environment. The resulting investigations indicate that not all properties of some insecticides are compatible with the environment.

The toxicity varies within each class and between classes. It cannot be said that one class is absolutely more toxic than another. The relative toxicities of most of the compounds of Table 10.5 are given in Table 10.6. These toxicities are expressed in 50% lethal dose values (LD_{50}). This term represents the quantity of insecticide which, when administered in a single dose, is lethal to 50% of a group of test animals. The value has been usually given as milligrams of insectiside given per kilogram of animal body weight (mg/kg or ppm).

Table 10.6. Relative Insecticide Toxicities.

Insecticide	*Class*	*Oral LD_{50} Value mg/kg or ppm*
DDT	Organochlorine	113
Methoxychlor	Organochlorine	6000
Aldrin	Organochlorine	39
Dieldrin	Organochlorine	46
Parathion	Organophosphorus	3.6
Malathion	Organophosphorus	1000
Carbaryl	Carbamate	540

The data of Table 10.6 have been for animal tests and, of course, similar data have been not available for humans. However, an extrapolation to human populations has been possible in a general way, for it is usually true that insecticides highly toxic to experimental animals are highly toxic to man. This generalization has been based primarily on inadvertent human experiments. Accidental contamination of food products (usually wheat and flour) has resulted in some epidemics of insecticide poisoning. Accidental parathion contamination of this type caused 102 deaths in India during 1958, and 88 deaths in Colombia during 1967.

Biochemical research has given some evidence which is concerned in the actual mechanisms by which these materials cause death. The autonomic (involuntary) nervous system is affected, causing tremors, convulsions, and eventual) death for insects, birds, and mammals.

The site of toxic activity for organophosphorus and carbamate insecticides has been the synaptic gap of nerves. A nerve impulse moves along a nerve fiber electrically until this tiny gap gets reached. The impulse triggers the release of a molecule of the compound acetylcholine, which quickly diffuses across the gap (a distance of 2-5 millionths of an inch) and is accepted by another nerve fiber. The molecule of acetylcholine triggers an electrical impulse which travels along the second fiber. The acetylcholine molecule will

continue to send impulses down the second fiber until it is chemically changed. An enzyme is present at the receptor site which quickly changes acetylcholine into a nonactive molecute before more than one impluse can be triggered. This enzyme, acetylcholinesterase (ACHE) is attacked and deactivated by organophosphorus and carbamate insecticides. With the means for its deactivation removed, acetylcholine triggers impulse after impulse down receptor nerve fibers. This causes tremors in the involuntary muscle system, convulsions, and death.

The mechanism by which organochlorine molecules operate toxically has been not as well understood. It is thought that they tend to dissolve in the fatty membrane surrounding nerve fibers, and there interfere with the vital transport of ions in and out of the fiber. This latter process gets involved in the transmission of electrical impulses along the fiber. Again, the effects have been tremors and convulsions.

Degradation of Chemical Breakdown

The majority of insecticide molecules placed into the environment have been not consumed by the pests they have been meant to destroy. A question of vital importance has been : What happens to that majority of molecules not consumed by the pests ? How rapidly do they break down or degrade in the environment ? The chemical structure of the insecticide has been the major factor involved in the rate of degradation. Insecticides of the same class with similar structures will be have similarly, but not identically, to one another during degradation.

Organophosphorus and carbamate compounds are generally able to degrade quite rapidly into simpler substances. Organochlorine compounds generally persist unchanged in the environment for longer periods of time.

It must be emphasized that even though chemical structure has been the major factor involved, environmental conditions may also influence degradation times. Examples of these other conditions

have been : soil type, amount of organic matter present, temperature, and extent of cultivation.

The complete chemistry involved in the degradation of insecticides has been not known. Organophosphorus and carbamate compounds degrade by means of hydrolysis (reaction with water) reactions to yield essentially nontoxic products. Organochlorine molecules do not get hydrolysed but must be broken down by slow microbial degradation. Because the reaction has been so slow, much of the material has been volatilized or leached from the soil before degradation is completed. Another important difference has been that the degradation products have been usually toxic and persistent in the environment.

Pollution Problems Associated with Pesticides

Although pesticides furnish several benefits, they entail a number of risks and problems. One is their toxicity or their potential for inducing tumors, cancers, or birth detects. The World Health Organization estimates that 500,0C0 pesticide poisoning cases occur annually in the world and that 1% are fatal (5000 deaths/year). In the early years of modern pesticides (1940—1960), pesticide manufacturers and users evaluated the safety of a pesticide almost solely in terms of its short-term effects on people or on plants and animals of obvious economic interest. Some pesticides, however, have been found to cause cancer or tumors in laboratory animals. Many scientists believe that positive animal test results indicate a possible cancer hazard to people. Moreover, the tumor-causing agents must be considered to be cancer-causing agents as well ; this view is supported by many scientists but questioned by others.

When it appeared that some pesticides might cause cancer, another pesticide-related problem emerged. The property of persistence was desirable, provided people were not killed or made ill, since the more persistent a pesticide, the less frequent the need for applications. Long persistence, however, also means more exposure

of a population to any harmful effects and more time to destroy nontarget organisms. The worldwide antimalarial program still finds DDT it most valuable weapon, because DDT is inexpensive, easily made, nonlethal to humans, and very persistent.

The risk of using DDT in the antimalarial program is still judged as less, statistically, than the benefits gained by its use. Any action concerning the use of any pesticide, including no action at all, entails both risks and benefits. The existence of a risk—benefit ratio has not been at issue. In many cases, however, those enduring the risks are not the ones who receive the benefits. A risk—benefit ratio approach is thought to be valid only when the risks and benefits involve the same population. At the heart of many environmental controversies are the moral questions of the extent to which society as a whole may impose risks and costs on a few and the extent to which a few may deny benefits to society as a whole.

The interaction of one pesticide with another sometimes causes the overall effect on human health to be more serious than the sum of the individual effects. These interactions have been studied in only a few of the almost limitless number of combinations, and much more research is needed. Until each combination has been tested and evaluated, mixed formulations of pesticides should be avoided by the nonexpert. If one component deactivates an enzyme used by the body to detoxify another component, the second component becomes much more toxic in combination with the first than it is alone.

Pesticides, pasticularly insecticides, are broad-spectrum compounds. They kill or harm many species including nontarget forms of life, creatures in the "innocent bystander" category. Carbaryl, for example, an insecticide used against crop pests, is extraordinarily lethal to honey bees, which are often essential for pollinating crops. Toxaphene causes deformed backbones in fish. DDT or its breakdown products affect the breeding success of birds. Many marine and freshwater organisms absorb pesticides from their surroundings

faster than they eliminate them. The next larger organisms that feed on the smaller ones may thereby receive dangerous doses or pass the poisons up the food chain to fish or birds or mammals important to people in economic or aesthetic ways. One technique in the reduction of damage to nontarget organisms is to use an attractant that lures the insect pest to a trap or to a site baited with insecticide (see Attractant). Spreading and drifting of an insecticide can be controlled by encapsulating the material in small beads made of a porous substance. The beads can be more accurately placed than can dusts or solutions spread by sprays, and the pesticide slowly diffuses through the wall of the capsule.

Even before the use of DDT, some organisms develop resistance to some pesticides. The survivors of a chemical raid on a pest population are generally the individuals having genetic traits that help them resist the action of the poison. Their offspring inherit this resistance. To fight the newer, more resistant forms, pest control scientists and operators escalate the insecticidal war by recommending higher doses of the poisons. The only alternative may involve the development of new pesticides.

It should come as no surprise that pests themselves are plagued by pests. One insect can make its meal out of another. Insecticides of broad toxicity tend to destroy all insects, but when the target pest rebounds, sometimes its natural predator fails to return.

DDT--A Controversial Compound

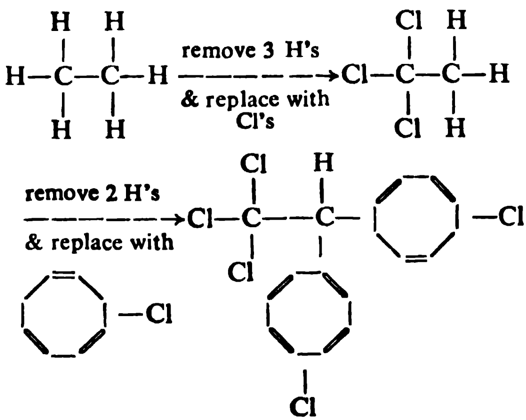
In order to illustrate the benefits obtained, problems encountered, and chemistry involved when pesticides are used, a detailed discussion of DDT will be presented. DDT has been chosen because it has been the most commonly used and most widely studied insecticide.

The story of this well-known substance has been one of rags to riches to rags. The compound has been in the news almost continuously since the late 1940s when it was first widely used as an insecticide. Twenty years ago, all comments about DDT had been

of a positive nature. It had been a relatively new compound, and the short-term effects of its use against agricultural and health pests were truly spectacular. Today, most statements concerning DDT have been negative. The change has taken place because of recent discoveries of the nature of its long-term effects on the environment, some of which are very detrimental.

It must be remembered that, although the following discussion deals only with DDT, other insecticides are having similar properties and some have similar long-term effects. Thus, much of the discussion may be applied to insecticides in general.

In 1874, Othmar Zeidler, a German chemist, synthesized the compound dichlorodiphenyltrichloroethane (DDT) as part of his doctoral research. The compound was not particularly unusual, having been synthesized by simple substitutions on the common ethane molecule.



DDT

Ethane

He published his work as a short note in a journal and the compound lay forgotten for many years.

Sixty-five years later, this same compound was "rediscovered" by a Swiss entomologist, Paul Mueller, who was studying the usefulness of various compounds as insecticides. He found Zeidler's

compound to be extremely toxic to insects. The Swiss firm for which he worked began immediately to manufacture the substance. In 1942, this firm delivered 6 pounds of the compound to the U.S. for testing.

The onset of World War II had deprived the U.S. of its supplier of pyrethrum, a louse control agent, and the military quickly found the new compound useful as a delousing agent. Other successful applications of the new insecticide followed rapidly. DDT was heralded for its success in halting a typhus epidemic in Italy during 1943-44. As a result of the use of DDT, World War II was the first war to claim more dead by combat wounds than by insect-spread communicable diseases.

After the war, DDT was effectively used to combat the insect carriers of malaria, yellow fever, and typhus. Millions of houses and people were dusted and sprayed with the compound in all-out campaigns against fleas, houseflies, and mosquitoes. Literally millions of lives had been saved by the material. Statistics show that DDT campaigns in Ceylon reduced human mortality by 34% in a single year. Such crop pests as the cotton boll worm were brought under control. The increased crop yields provided economic benefits for the farmer.

In 1948 Paul Mueller was awarded the Nobel Prize in chemistry for his discovery of the insecticidal properties of DDT. The compound was at the zenith of its popularity.

Problems with DDT

Due to the tremendous success of DDT in controlling pests, its use in large quantities was continued through the 1950s and into the early 1960s. This large scale use led to two problems that only slowly became apparent and eventually led to a decrease in use of DDT.

1. Certain insects got developed a resistance or immunity to the compound.

2. Natural processes were found to spread DDT from target areas to non-target areas and ultimately throughout the environment.

As early as 1947, Italian researchers reported that the housefly had been becoming immune to the compound. Other researchers reported similar findings from many locations in the world. Apparently the attempts to completely eliminate certain insects caused the death of the vast majority. The few remaining, however, were evidently immune to DDT. These naturally immune specimens were now reproducing and developing resistant strains. This acquired immunity was the motivation behind the development of many new insecticides.

The movement of DDT throughout the environment occurs because DDT has been a persistent pesticide that remains chemically unchanged in the environment for long periods of time. Pesticides of this type show an advantage over non-persistent types by remaining effective over long periods of time and requiring fewer applications. An obvious disadvantage has been that the longer persistance increases the chances that DDT will move out of treated areas and damage non-target organisms. Today, DDT residues have been found throughout the environment and in many living organisms. The accumulation of DDT in the marine environment is of particular concern.

Evaluation of DDT Effects

The determination of DDT effects on non-target organisms has been not a simple process because of the many variables at work in nature. Imagine, for example, that the population of a certain species of wildlife has been declining in a particular geographic area. Numerous questions must be answered to uncover the causes of the decline. Several typical questions are :

1. Is the species dying or is the decline caused by unnatural migration ?
2. If migration is the answer, what is causing the migration ?
3. If the species is dying, are pesticides or other factors at fault ?

4. If pesticides are at fault, how were they transported to the non-target species ?

5. Again, if pesticides are involved, what physiological effect does the killing and what pesticide dosage is required ?

Answers to these and other similar questions have been nearly impossible to find, when natural populations have been involved, because of difficulties encountered in trying to single out each factor and determine its contribution to the over-all problem.

The declining numbers of some kinds of birds of prey has been an example of the problems encountered when dealing with natural populations. Some wildlife biologists suspected that DDT residues had been contributing to the decline but they could not be sure that other factors such as the urbanization of the birds' natural habitat were not involved. Birds were reared in the laboratory, and fed measured doses of pesticides in concentrations similar to those present in the natural habitat. Only after these experiments could the pesticides be identified as the agents causing the observed effects. Much of the evidence quoted in the following discussions got gathered from similar laboratory experiments concerning the effects of DDT.

Effects of DDT in the Marine Environment

It is to be noted that the oceans are the ultimate accumulation site for as much as 25% of all DDT used to date. This accumulation results because DDT very easily reaches ponds, lakes, and rivers in a variety of ways, including the following :

1. DDT could be applied directly to water in the form of aerial sprays to control water-borne insects.
2. DDT may accidentally fall on water when it is sprayed from airplanes to control forest or agricultural pests.
3. DDT may be carried down from the atmosphere in rain. Rainwater samples have been found that are having up to 0.34 ppb DDT.

4. DDT residues may reach water in surface runoff from soil. The pesticide is relatively insoluble in water but it strongly adsorbs to organic matter like that present in many soils. When streams or rivers become contaminated with relatively high levels of DDT it has been usually through wind or water erosion of treated soil.

Even though large amounts of DDT have reached the waterways, and ultimately the oceans, the actual concentration in the oceans has been quite low because of the dilution effect exerted by the huge volume of ocean water involved. Concentrations of DDT in the parts per billion range for fresh water and parts per trillion for ocean water have been typical.

Why has been there such great concern about DDT in the marine environments if concentrations are so low ? Much of the concern has been generated by the ability of many plants and animals to concentrate DDT (and other similar pesticides) in their body tissues. Oysters and water fleas have been extreme examples of organisms with this ability.

Oysters have been able to concentrate DDT from levels of 1 ppb in seawater to levels of 700 ppm in their bodies. The body concentration has been 70,000 times as large as the seawater concentration. Water fleas have been even more efficient and can concentrate DDT levels of 0.5 ppb in seawater by a factor of 100,000 times.

Typical values for a food chain concentration pattern have been given in Fig. 10.2.

Laboratory and field studies of fish point out some of the possible problems that exist and are related directly and indirectly to the presence of DDT in marine and other aquatic environments.

1. DDT can induce behavioral changes in fish that could lead to reproduction problems. New Brunswick salmon from a DDT-sprayed region were found to be unusually sensitive to low temperatures and, as a result, chose to populate waters of higher tempera-

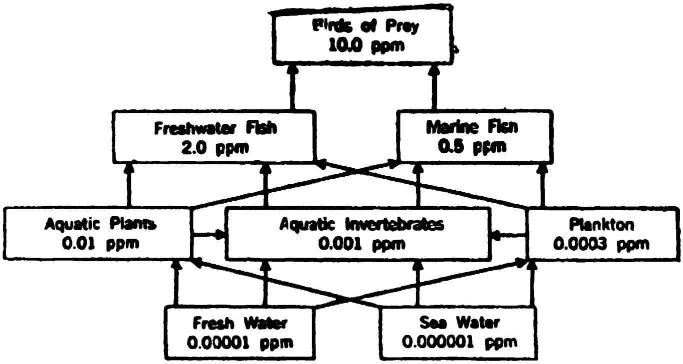


Fig. 10 2. A typical food-chain concentration of DDT.

ture than their normal habitat. If this occurred in nature, salmon might lay their eggs in regions where the young could not survive. A similar result was found in mosquito fish. After exposure to low DDT levels of 0.1 to 20 ppb for 24 hours, mosquito fish showed a definite preference for waters of higher salinity than did unexposed fish.

2. DDT in fish eggs affects the mortality rate of the young. DDT tends to concentrate in the fatty tissues of fish. The ovaries contain such tissues and the concentration of DDT in these organs can lead to high concentrations in eggs. In the speckled sea trout, DDT residues in ripe eggs are at a level of about 8 ppm. This level has been higher than the 5 ppm level found to cause 100% failure in the development of young fresh-water trout.

Lower DDT levels may also be injurious. It has been found that when levels of DDT and its metabolites are higher than 0.4 ppm in the eggs of hatchery trout, the mortality rate in the resulting young ranged from 30% to 90% in the 60-day period following hatching.

3. DDT may be directly toxic to certain species of fish (especially the young) and cause large fish kills. The LC_{50} value (concentration of DDT in the water which kills 50% of the test fish)

for various common fish is in the range of 1-10 ppb. Typical LC_{50} values for a 96-hour exposure have been : Coho salmon—4 ppb ; rainbow trout—7 ppb ; and yellow perch—9 ppb.

4. DDT may accumulate in the body tissues of commercial fish to an extent that human consumption of the fish is possibly dangerous. The fish contained DDT at concentrations in the 10-20 ppm range.

Effects of DDT on Birds

It is now clear that residues of DDT occur in the tissues and eggs of many species of birds. The process of biological concentration repeated through several links in the food chain appears to be occurring here as it does in fish. Those species with highest DDT concentrations are the fish eating birds followed in order by flesh eaters, flesh and plant eaters, and plant eaters.

The accumulation of lethal levels of DDT through food consumption has been known to take place in birds inhabiting areas where DDT use is great. The application of DDT on elm trees for the control of Dutch elm disease has resulted in a high mortality rate for robins and other birds. Some of the sprayed DDT apparently drips to the ground and concentrates in the soil. Soil concentrations may reach levels as high as 18 ppm. This DDT is ingested, along with soil, by earthworms which in turn are eaten by robins and other birds.

In a 1981 study conducted in environments having DDT-treated elms, pesticide residues were found at a 9.9 ppm level in soil. This concentration increased to 141 ppm in earthworms and to 444 ppm in the brains of adult robins. In another study conducted on dying robins collected from a DDT-treated area, the median residue of DDT in the birds' bodies was 3 mg. Calculations indicate that the ingestion of fewer than 100 earthworms would make a robin to accumulate the lethal 3 mg dosage.

Sub-lethal dosages of DDT have been reported to cause significant changes in the physiology of some species of birds. A cor-

relation has been found between the amount of DDT residues in eggs and the egg-shell thickness of a number of birds of prey. This is thought to occur as a result of DDT inhibition of an enzyme that controls calcium metabolism in the birds, less calcium is deposited in the egg shells and the resulting fragile eggs are less able to withstand the rigors of incubation. This results in a large amount of reproductive failure. In a laboratory study, American sparrow hawks were fed a diet for two years that contained DDT residues at environmental concentrations. The hawks showed an average 10% decrease in egg-shell thickness.

Other pesticide effects on reproduction have been known besides egg-shell thinning. A study of finches found the ovulation time doubled when the birds were fed DDT along with their normal diet. This, of course, caused an increase in the time required for a new generation to be produced.

DDT in Humans

Man stands at the top of every food chain in which he is involved, and accumulation of DDT should therefore occur.

It is believed that the main source of DDT in man is food, although home use and dust-laden air have been implicated as well.

The available evidence concerning the effects of current human DDT levels has been limited. Much that is known is the result of case studies of accidental poisonings. A detailed survey of such incidents reveals that the general effect on man is that discussed before, increased excitability of the nervous system.

It appears that present levels of exposure to DDT among the general population are not produced any observable adverse effect when used in controlled studies conducted on volunteers.

In spite of the lack of evidence concerning adverse effects on humans, it has been obvious that DDT is very suspect at this time. Its effects on the environment seem irrefutable. The compound has now completed the rags to riches to rags story.

At the present time, a total ban on DDT use has been considered. The complete ban has been a matter of controvesy much like the situation with detergent phosphates. Those against a complete ban have presented the following arguments and proposals :

1. No human has yet been seriously injured as a consequence of normal DDT use.

2. The effects on birds and fish appear to reflect results of heavy overdoses rather than proper use. There has been little doubt that this has occurred. Aerial spraying and annual "insurance" treatment of large areas (whether pests were present or not) have contributed significantly to the amount of residues present in the environment.

3. The establishment of a corps of specialists trained in the proper use of DDT could minimize its disadvantages. Only these specially trained individuals would be licensed to use the material and would know where it could be legally used and in what maximum dosages.

4. If DDT is totally banned, other more costly chemical pesticides must be used in its place since alternate control methods are not yet available (see the next section of this chapter). Many of the known substitutes degrade more rapidly but are much more toxic. Parathion, for example, has been 30 times more toxic than DDT and accidental poisonings with this material have already taken place.

5. It is not in the best interests of world-wide health to confront readers of newspapers and magazines in India, for example, with headlined articles about total DDT bans in affluent countries. This could make groundless anxieties about the substance being used selectively to alleviate desperately serious health problems in backward countries. Such programs definitely require an insecticide that is cheap, persistent, effective, and safe to those contacting it under proper conditions. DDT is an insecticide with these characteristics.

Those in favor of the ban say :

1. The effects of DDT on humans have been not known and it is better to be safe than sorry.

2. Birds and some fish have been experiencing reproductive failure and direct poisoning as a result of DDT in the environment.

3. Many new pesticides, although more toxic, degrade faster than DDT and so do not persist in the environment.

Both sides agree that the best solution to the problem has been the development of alternatives to DDT-like chemical insecticides. This will probably require an appreciable amount of time.

Alternatives to DDT-like Chemical Pesticides

The harmful effects of DDT on the environment can be expected in some degree for other similar chemical compounds. Because of these problems, interest has been growing in devising alternate pest control methods. These alternatives are in various stages of development and some require more basic research before their worth can be evaluated. Some possible alternatives are as follows :

1. *Use of biological controls.* This approach involves the use of natural predators, parasites, and pathogens (disease-causing organisms) to destroy insects. The potential value of such controls appears promising since such organisms, particularly pathogens, are very specific toward their hosts and remain inactive against others. The principal hazard of this approach is the possibility that predators introduced to control pests might themselves become a problem.

The classical biological control of pests is to introduce other insects or microorganisms that prey on the pest, are parasites to it, or give the pests a disease. For example, the virus *Borrelina campeoles* is deadly to the alfalfa caterpillar. Japanese beetle grubs are infected by a particular bacterium (*Bacillus* sp.). Tachinid flies attack certain of the insects that damage trees. The nuclear poly-

hedrosis virus of *Heliothis zea* is used against the cotton bollworm and the tobacco budworm. Finding insect parasites, predators, and pathogens for pests, however, is a long and difficult effort, and insects can develop resistance to such diseases too. In the entire world only slightly more than 100 insect pests are successfully controlled by these approaches (and only 46 in the United States). Integrated control, the combining of biological control with pesticides, is being increasingly used to reduce overall dependence on chemicals.

2. *Development of resistant varieties of plants.* Agricultural researchers have succeeded in developing varieties of plants that are resistant to specific insects and diseases. Such plants, once developed, represent a safe, cheap, and practical method for overcoming insect pests. The use of resistant plants has to main drawbacks. Usually, many years are required two develop a commercially acceptable plant. After plants are produced, new strains of insects or plant pathogens sometimes develop to which the "resistant" plants are no longer resistant.

The weapon in pest control which is safest to the environment is the development of hybrid species of food and fibre crops that are resistant to their traditional enemies. For example, losses due to corn borers or sugarcane borers have been cut by 70% in new varieties of corn. Strains of cereal grains such as barley, corn, oats, and wheat have been developed that resist leaf blights and rusts. It takes years, however, to develop the hybrids, and eventually they in turn will fall victim to their own predators.

3. *Use of attractants.* In their search for food, insects respond to various chemical substances in plants. They also respond to chemical sex attractants produced by other members of their species. Light and sound are also known to attract some types of insects. Attractants are being used to lure insects into traps where they can be killed. Considerable effort is being devoted to the tasks of isolating, determining the structure of, and synthesizing attractants in order to obtain quantities large enough to be tested as possible control agents for several major insect pests.

4. *Genetic control.* In this approach, sexually sterile insects are released to mate with normal insects. The native population of insects is first reduced using other methods. While this is being done, insects are reared in the laboratory and the males are sterilized by radiation or the use of sterilizing chemicals. The sterilized males are then released into an infested area. The number of sterile males released is planned to be much greater than the number of normal males in the natural population. As the release of sterile males is done periodically and with each succeeding generation, fewer and fewer productive matings take place. Eventually the insect population is reduced to zero.

5. Self-destructing Virus

British scientists (1988) are seeking government approval to test one of a new breed of genetically engineered viruses that will kill insects and then destroy themselves.

Reporting this at a London conference, Professor David Bishop from the Institute of Virology at Oxford said the plan was to try out a self-destructing virus in Scotland on a moth caterpillar that attacks pine trees.

He said successful laboratory experiments had already been carried out to modify the genes of a microbe known as baculovirus so that it would "selfdestruct" once its job was completed.

Professor Bishop believes it will be about five years before a modified baculovirus and a number of other genetically altered microbes come into general use as an alternative to chemical sprays for controlling agricultural pests.

He said a method of biological control could be aimed at one particular pest without worrying if it would affect other wildlife, animals or people.

Professor Bishop said it nevertheless was prudent to make sure new genetically created organisms released for biological control would eventually kill themselves.

The Oxford research team had therefore applied for permission from a government committee to try out the self-destructing virus in Scotland.

The types of virsuses chosen by Professor Bishop's group already exists in nature. Two have already been used in their non-altered form against the caterpillars of the pine sawfly moth and the pine beauty moth. The micro-organisms are sprayed over the leaves and swallowed when a hungry caterpillar chews a leaf. The object of genetic engineering is to make the virus a more potent toxin to the catespillar.

The self-destruct mechanism occurs because viruses have a "protected" and "naked" form, according to Professor Bishop. Protection is given by a surrounding coat of protein that protects the viral particle. By deleting one of the genes in the virus, the protein coat is absent. With no protection, the microbe is easily destroyed when it is shed by a dead caterpillar.

6. *Bioenvironmental control.* Certain common practices or procedures can be changed in a way that adversely affects insect pests. Stalk cutting and disposal of plant parts normally left in fields following harvest is an example. Insects that live through the winter in such stalks and attack crops the following year are dramatically reduced by this practice. Some insects can be controlled in field crops by delaying the planting until the insects have passed through their most destructive stage of development.

7. *Hormone manipulation.* This practice can disrupt the life cycle of insects and limit the number that survive. Considerable research has been done with hormones that help regulate insect body functions. For example, the presence of juvenile hormones in an insect allows it to grow but not to mature. The absence of juvenile hormones allows a young insect to become an adult. If insects- were to receive doses of juvenile hormones when they would normally be maturing, development to the adult stage would not take place. Substances, similar to the juvenile and other hormones, have

been found in some plants. These substances are being studied to determine their usefulness in the control of insects.

High hopes exist for alternatives to chemicals, but it appears that for the present we must depend on chemicals used selectively and prudently to control insect pests.

A guideline, resulting from recent experiences with insecticides, is that persistent substances should be released into the environment only when absolutely necessary. This means that DDT-like insecticides should be used only to protect human health or life-supporting food supplies and only under controlled conditions when no satisfactory alternative is available.

11

Microbial Systems

INTRODUCTION

In all natural systems certain materials have been taken in by plants, converted to complex molecules, and incorporated into plant tissues. These materials then pass into various animals because of the animals grazing on the plants. When the plants die and the animals excrete waste materials or die, these materials get reconverted by a large group of organisms, called *microorganisms*, into a form where they can again be used by plants. Thus materials tend to cycle from plant to animal to microorganism and back to plants in what is called a *food chain*.

Microorganisms, also known as *protists*, have been vital to the function of food chains because it is by their activity that plant and animal residues are converted into the proper form for plant use. Hence all life ultimately depends upon the functioning of microbial systems.

Unlike the larger organisms which exhibit differentiation and specialization of cells into tissues, organs, and so on, the microorganisms have been single-celled and perform all their necessary life functions within their single-cell. Microorganisms include bacteria, blue-green algae, fungi (yeasts and molds), green and brown algae,

the protozoans, and the viruses. The viruses, unlike other protists, have been non-cellular and exist as naked protein. Except for the viruses and the bacteria *Chalmydia* and *Rickettsia*, all protists have been capable of independent life.

MICROBIAL RELATIONSHIPS

Microorganisms rarely takes place in natural systems as pure cultures consisting of only one type or single population, but take place as mixed populations or communities containing several different types. Microbial communities have been constantly changing in response to both environmental factors and the interactions of other organisms within the microbial, plant, and animal community.

The interaction among organisms of different species is called *symbiosis*. The symbiotic relationship may result in one of three direct effects that may get exerted on the participating organisms : commensalism, mutualism, or parasitism. *Commensalism* has been an example of a symbiotic relationship in which one organism benefits from the association while the other organism is unaffected. *Mutualism* has been a relationship in which each organism involved derives benefit. In *parasitism* one organism derives benefit while the other, termed the host, is harmed. Parasitism has been distinct from predation in that a predator ingests its prey while a parasite insidiously removes materials from the host and in so doing derives nutrients in a manner that gradually harms or weakens the host.

There has been an indirect relationship, called *saphrotism*, which has been important in coastal marine systems. Saphrophytes are involved in the breakdown of various materials, such as marsh grass, into smaller particles termed *detritus*. The detritus is then used as a food source by the animals present in these systems. Thus, in the saphrophyte chain, material cycles from plants to microorganisms to animals, rather than from plant to animal to microorganism.

TYPES OF MICROBIAL DECOMPOSITION

In natural systems microorganisms carry out the decomposition of plant and animal residues by three major mechanisms : *aerobic, anaerobic*, and *facultative decomposition*. The bacteria active in performing these processes are called aerobic, anaerobic, and facultative bacteria.

Aerobic decomposition needs the presence of oxygen, and this oxygen gets converted to water in the process. In *anaerobic decomposition* the presence of oxygen is not needed ; other materials, such as nitrite (NO_2) and nitrate (NO_3), are utilized in place of oxygen. *Facultative organisms* can perform their functions in either aerobic or anaerobic situations. If the system is aerobic, the facultative microorganism will use oxygen, whereas if there is an absence of oxygen (anaerobic system), these microorganisms are capable of using nitrite and other materials in place of the oxygen. In some water-treatment methods the unique properties of aerobic and anaerobic microorganisms have been used utilized to purify wastewater.

HUMAN IMPLICATIONS

The microbial populations in water tend to change and fluctuate in response to the source of the water in which they occur, as well as in response to the composition of the various materials found in the water. The origin of these microorganisms has been generally the result of surface runoff, precipitation that carries microorganisms attached to dust particles to earth and/or the addition of wastewater to waterways, bays, lakes, and so on. Generally, the microorganisms that have been derived from runoff from uncontaminated terrestrial areas and from precipitation are not harmful to man.

The microorganisms derived from wastewater may, on the other hand, be harmful. These microorganisms are called *pathogens*. Generally, wastewater is having both pathogenic and non-pathogenic

forms. The danger of disease arises when wastewater enters water supplies intended for human use.

Diseases commonly transferred in this manner have been those of enteric origin (those caused by microorganisms found in the intestinal tract). Microbial pathogens found in excretory matter include *Shigella*, the agent of bacillary dysentery ; *Salmonella*, the bacterial agent of typhoid fever ; *Vibrio*, the agent of cholera ; *Endamoeba*, a protozoan responsible for amebic dysentery ; and two viral agents, polio and hepatitis.

The threat of disease by contaminated water supplies has been of prime concern ; thus constant testing of water supplies is essential. Since the routine examination of drinking water for the presence of intestinal pathogens is difficult and costly to perform, water supplies are generally tested for the presence of non-pathogenic forms like *Escherichia coli* and *Streptococcus fecalis*. These organisms always occur in the intestinal tract but are not routinely found in soil and water. Thus when they are detected in water supplies it is assumed that the water is contaminated. These organisms, therefore, are used as indicators, because their presence indicates the possibility that other intestinal microorganism may also be present the intestinal pathogens. All qualitative bacteriological testing of water is based on the identification of these indicator species. Table 11.1 summarizes the major microbial indicators.

Table 11.1. Microbial Indicators of Water Quality

Indicator	*Specific Organisms*	*Use*
Fecal coliforms	*Escherichia coli*	Indicator of fecal contamination by warm-blooded animals
Total coliforms	*Escherichia aerobacter*	Indicator of coliforms originating in soil and intestines of warm-blooded animals
Fecal streptococci	*Streptococcus faecalis* *S. durans* *S. faecium* *S. bovis* *S. equinus*	Used to judge the probability of human or livestock contamination source ; used in conjunction with fecal coliforms
Algae	Polluted water : *Oscillatoria*, *Spirogyra*, *Anabaena*, others Clean water : *Ulothrix*, *Galothrix*, *Cyclotella*, *Diatoma*, *Chrysococcus*, others	Large accumulations of polluted-water forms indicate advancing eutrophication
Sulfur bacteria	*Thiobacillus* Other colorless, green and purple sulfur bacteria, purple sulfur bacteria	Accumulations indicate sulfur-bearing wastes, particularly containing hydrogen sulfide
Iron bacteria	*Gallionella* *Ferrobacillus ferrooxidans* Others	Accumulations in natural waters indicate iron-bearing wastes
Standard plate count	Various	Empirical techniques for determining general bacterial density ; identification permits judgment concerning relative impo ance of parasites, pathogens, and beneficial saprophytes

12

Eutrophication

INTRODUCTION

Lakes, large and small, are constantly being enriched by organic matter from decomposing plant and animal remains, providing nutrition for algae and larger aquatic plants. This fertilization, whether from natural sources or man-made, is called *eutrophication*, from the Greek meaning "well fed". This condition occurs often in nature and is not necessarily bad, for the organic material means food for fish and other aquatic life.

But too much mineral nutrient in the water might be more serious than too little. Many people have seen the reddish or greenish cast of lakes, bays or coastal areas in summer or fall caused by enormous numbers of algae and other phytoplankton. Their presence has been often followed by the death of fish and other water life, sometimes on a massive scale. Such occurrences have the result of microscopic life having become overabundant. When the algae and other plankton die, decomposition of the superabundance of organic material makes the oxygen in the water to become suddenly depleted. Water cannot absorb replacement oxygen fast enough to take care of the needs of the living organisms. They suffocate. Also, toxins have been sometimes produced.

The "red tide" that is frequently seen along the coasts of California, the Gulf of Mexico, and India has been caused by the buildup of microscopic *dinoflagellates*. These have been single-cell swimming organisms that have some of the attributes of both animals and plants. They impart a red or dirty brown coloration to the water and at night create a spectacular display of luminescence in the froth of wave or in the wake of a boat. Their most injurious effect has been the production of a lethal poison called *saxitoxin*, which accumulates in the bodies of clams and mussels. People who eat them are liable to be stricken with "paralytic shellfish poisoning," a dangerous form of food poisoning having a 21 per cent mortality rate. The red tide along the coast of India has been thought to be caused by an overabundance of mineral nutrients deposited by the heavily mineral-loaded run-off of flood water during the monsoon rains. Along the California coast, it has been suspected that the nutrients from sewage outfalls contribute to excessive growth of the organisms when suitably high temperatures and other favorable conditions prevail.

In contrast to many of the land areas where the scarcity of water has been the chief limitation to the growth of vegetation, the oceans are afflicted with a lack of nutrients. It has been the most critical factor, but not the only one, in determining the growth of the small plant and animal life of the sea, called plankton.

Most of the open sea has been a biological desert, an essentially barren area which is comprising 90 per cent of the ocean or nearly three-fourths of the earth's surface. Half the world's fish supply has been produced in coastal waters and in a few offshore areas of comparably high fertility. The other half has been produced in regions of upwelling water that total no more than 0.1 per cent of the ocean's surface. Thus, the most productive portions of the ocean —the coastal waters—have been those which have been the most polluted and where the marine life has been the most susceptible to disturbances in the environment.

DISCUSSION

The expression eutrophication stands for the enrichment of the nutrient supply in stagnant waters. It is a rather complex concept. In order to be able to understand it, one must be familiar with certain basic principles of the nutrient cycle in the life of lakes. Aquatic organisms are interrelated with each other by means of the food chain. When examining the manifold aspects of nutrition in a lake, one might recognise a certain order. The basis of this regular order has been that by using solar energy aquatic plants (also the most important planktonic algae) synthesize organic matter from water, CO_2 and mineral salts. A simplified equation for this has been the following :

$$6\ CO_2 + 12\ H_2O \xrightarrow[\text{pigment receptor}]{\text{light}} C_6H_{12}O_6 + 6\ H_2O + 6\ O_2$$

This has been a primary product which has been transformed and accumulated at a higher level by aquatic invertebrates. The latter have been then consumed by fish.

Concerning their functions, aquatic organisms playing a part in this food chain can, principally, be divided into two groups : constructive organisms which build up organic matter and transferring organisms. According to their functions within the group of transferring organisms, one can distinguish rebuilders, returners and decomposers. By rebuilders we mean such organisms which directly or indirectly feed on aquatic vegetation. Algae filtering zooplankton members, non-predatory fish feeding on them, or even carnivorous ones (pike, European eels, *Silurus glanis* L.) can equally be classed as rebuilders. Recuperant organisms are also animals feeding on plant and animal wastes. Their significance is interpreted variously in the literature in Hungary (Balogh 1953 ; Szabo and Marton 1956). Their real function is, among others, to consume bacterial colonies growing on detritus and by further splitting them up, helping bacterial decomposition. The expression returner, therefore, does not apply to the function of the animal group in question. The

detritus eating Chironomid (midges) larvae, the main natural food of non-predatory fishes are also such animals. The term *decomposer* organisms, refers mainly to bacteria. If quantitative relationships are regarded also in a feeding context, it can be observed, that the absolute quantities in the food chain exhibit a pyramid-like decreasing tendency.

Material recycling occurring in the life communities of lakes also means energy flow. Consequently, the feeding of organisms especially determines the energy flow. The different trophic levels to be found in life communities, which have been based on each other, can, therefore, be regarded as energy levels. These are denoted after the first letter of the English word "level" by λ. The number of these levels has been normally restricted to 4—5. These have been fed by differing densities of various species. A certain percentage of solar energy (λ_0) is transformed, in the course of photosynthesis, in the bodies of algae, where it represents a potential quantum of energy (λ_1). Members of the animal plankton (*e.g.*, Daphnia) consume a certain proportion of the plankton algae (λ_2) ; these are, in turn, consumed by zooplankton eaters (λ_3) *e.g.*, glass crab (*Leptodora kindti*) and non-predatory fishes belonging to the third level. The latter may, then, be consumed by carnivorous fishes (λ_4).

In reality the matter and energy flow occurring along the food chain has been far more complex. The connection between λ_1 and λ_2 in Lake Balaton has been a case in point. Food interrelationships between plankton organisms have been fed into a computer, type CDC 3300. It has been established that from among algae of the size 10—1,000 μ, only organisms of the size 10-40 μ were capable of reaching the second trophic level at a probability level of 0.1% Fig. 12.1). As only two (*Keratella tecta* and *Polyarthra vulgaris*) of the 3 rotifera species, to be taken into consideration in the transport of algae, occur in large numbers this can happen only to a small extent. Filter-feeding *Crustacea* are only slightly bound to algae of the size 10—20 μ (P=5%), which clearly supports the fact that the exploitation of organisms smaller or equal to 10 μ is greater (Gliwicz 1969).

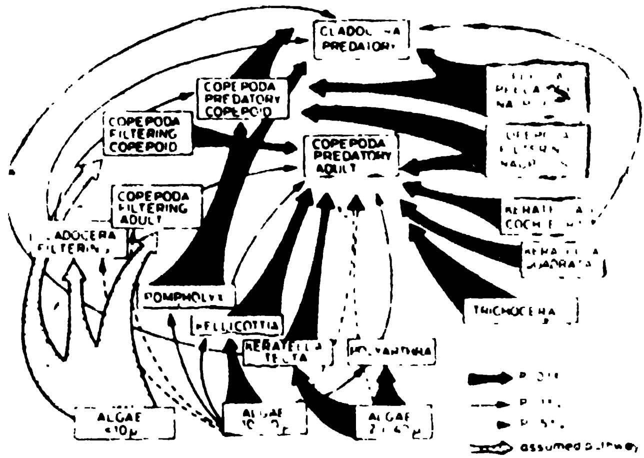


Fig. 12.1. Sketch of the food relations in the open water area of Lake Balaton. The arrows represent probability levels. (after Ponyi 1977)

Owing to this, experts have been of the opinion that in Lake Balaton the organic matter produced by primary production, in the form of particles larger than 10 μ, will hardly be capable of passing through the filtering-sedimenting system of Lake Balaton to reach higher trophic levels. Other data, too, seem to indicate the important role of bacteria and micro-algae in the plankton system.

When making a detailed study of a particular trophic level, it has to be observed that a certain quantum of energy is put into this level. The quantity of energy output has been less than the input. The above-mentioned loss of energy is caused by several factors : energy needed for self-preservation, energy loss because of cannibalism and the loss of potential energy volume caused by death.

Once a substance gets entered a living system a significant proportion of it will get involved in a perpetual circulation, whereas the energy bound to it will pass through the whole system only once. At the different levels, the organic matter gradually gives off its energy and becomes inorganic matter. Photosynthesis will then

build this inorganic matter into plants and the cycle starts again. The scheme outlined in Fig. 11.2 is a greatly simplified one. It must be taken into consideration that there have been also processes opposing biological recycling ; these lead matter and energy flow in the direction of abiotic transformations. Only that kind of organic matter will leave the circulation of substances of ecosystems, over which the coordinating effect (power) of the enzyme systems of living organisms has lost its power. This is generally the case when aerobic organisms have been subjected to anaerobic conditions. Their cell walls dissolve, enzymes embedded in the plasma are freed and an uncoordinated process will start. In the course of post-lethal biocatalytic processes, the condensation of phenols of different origin can be observed. These substances being already foreign to the structure of the organism do not take part in the material cycle.

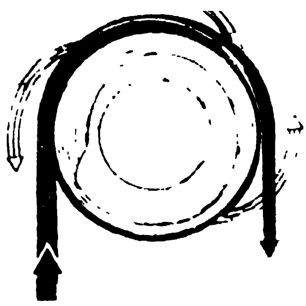


Fig. 12.2. Scheme of the matter and energy flow in a living community. Black arrow ; incoming and outgoing energy from the system : hatched arrow : amount of organic matter. Upon the net gain of solar energy, the amount of organic matter increases at the expense of inorganic matter. This relationship is reversed in the course of further processes. The three arrows pointing in the opposite direction to biogenic cycling represent the reverse process to "carbonification", when metter and energy are transferred by way of abiotic transformations. (Szabo and Marton 1956).

Such substances are the different components of humu. According to this interpretation, the energy-saving role of bacteria is relevant. Earlier it was believed that they, on the contrary, freed energy within the ecosystem (Szabo and Marton 1956).

Thus, it becomes easy to realise that the number of animal consumers is dependent on the feeding capacity of plants. The reproduction of aquatic plants has been, however, determined by the amount of nutrients available in the water. Therefore, similarly to other biological systems, the aquatic life of lakes is dominated by the "quasi-stationary state", which is maintained, principally, by the matter and energy turnover (Fabian *et al.* 1975). Apart from the thermodynamical interpretation, it has been also a characteristic of this special state that there are no "macroscopically" observable changes, though the building-up and decay processes constantly take place in the lake.

In spite of the fact that all the preconditions for the stability of aquatic life of lakes have been given, one is able to distinguish the following phases in it : *juvenile maximal* and *senile.* This can be accounted for by the fact that the functioning of aquatic plants, animals and bacteria, just because of changes in the margins of the lake, cannot be fully co-ordinated. Hence the decomposition of organic matter has been inadequate, *i.e.*, a certain proportion of organic matter collects in the sediment. Thus owing to its own nutrient production, the aquatic living space becomes rich in nutrients. This process is called eutrophication. Man-made effects can be able to accelerate this process, which is called artificial eutrophication. While the former process has been going on for thousands of years, the latter is taking place now, within a lifetime. Eutrophication can hardly be influenced. As artificial eutrophication is the result of the activities of man, it can be naturally controlled, slowed down or accelerated.

According to the impact of human activity on the eutrophication of lakes, five major groups can be distinguished : (*i*) The impact of river-regulation and water impounding works, (*ii*) agricultural

activity and its impacts, (*iii*) forest and sylvicultural works, (*iv*) industrialisation, (*v*) impacts of urbanization.

The impact of agriculture on the eutrophication of lakes is brought about by the rivers entering the lake and carrying a different quantity and quality of nutrients of agricultural origin. Mainly infiltration, agricultural effluents, less frequently wind or carelessness are the main means by which these substances get into water reservoirs. Nitrogen and phosphorus fertilizers play a significant role in the eutrophication of lakes. Nutrient enrichment manifests itself in the growing mass of algae and aquatic vegetation. Further the application of fertilizers is increasing at a considerable rate which calls special attention to the growing danger. It is practically impossible (in the case of nitrogen) or else very expensive, (for phosphorus) to remove these substances from watercourses.

The spread of intensive, factory-like livestock husbandry is another source of pollution. Slurry might flow directly into watercourses. Although, in Hungary, we have no available data on these processes as yet, according to foreign assessments they give rise to a significant problem.

Inadequate protection of the soil and obsolete agricultural practices result in significant amounts of top-soil getting into surface waters. This increases the total amount of nutrients available for plants by 1.49 mg/l. This source, which accelerates eutrophication, can be controlled only by soil-conserving cultivation that can be regarded, in this respect, as a system of water conservation and environmental protection.

The role of forests is not exhausted only in the transpiration of water and in the control of the level of sub-soil water, but they also play an important part in the binding of the soil. As a result of great efforts in reforesting, it has been achieved during the last decades that the area of forests exceeds 15% (Deri 1971). Forests, situated alongside waters to be controlled.

The impact of urbanization and industrialization on the process of eutrophication of lakes cannot be distinguished. That is to

say, in both cases, the production of mineral substances getting into the lake promotes the proliferation of algae and aquatic weeds. Here, too, nitrogen and phosphorus-containing substances are the most important.

ALGAL BLOOMS

Every lake or pond goes through a life cycle that may take from a few days up to thousands of years for the larger bodies of water. Each lake or pond faces the prospect of becoming more shallow with time as silt and organic matter are swept in by streams and run-off and deposited in the water. Shallow ends, often near the outlets of streams, lend to become marshes. Algae and other plants proliferates under these conditions and often appear as a green scum. We can see various stages in the life history of lakes, from those with fresh, clear, sparkling water to the shallow, growth-chocked, scum-surfaced swamps on the verge of becoming dead lakes.

In lakes and slowly moving waters that have been enriched, algal blooms or dense plant growth accumulate along the shores and in shallow portions where they may form decaying masses and foul-smelling scums. Blue-green algae of several types are the most troublesome in water warmer than 70°F. Sometimes a toxin, as yet unidentified, has been poisonous to livestock and wild animals.

Algal blooms have been sometimes caused by conditions that have been not related to added nutrients. Artificial warming of the water, such as that from cooling towers and condensers, may be able to stimulate the growth of blue-green algae. The elimination of other aquatic flora, either mechanically or by the presence of some toxic substance, is able to promote the growth of bloom-forming algae by removing competition for the available nutrient supply. The release of organic nutrients by the decomposition of aquatic plants killed by herbicides may cause an increase in algal growth, and the absence of plankton-feeding organisms may favor excessive production of bloom.

Algae, which have been the principal growth products of eutrophication, require at least fifteen elements to sustain growth. If any one of them has been in short supply, it will be a limiting factor in the growth and development of the algae. However, many of the essential nutrients, particularly the so-called micronutrients, have been nearly always present in abundance in lake waters. Also, algae normally have access to an abundant supply of carbon, especially from carbon dioxide in the air and from carbonates dissolved in the water. (Some scientific investigators believe that a deficiency of carbon dioxide can become a limiting factor.) Nutrients that are used by the algal plants in large amounts have been apt to be the most important in determining the rate and degree of growth. The primary plant nutrients have been nitrogen, phosphorus, and potassium. Of these three, nitrogen and phosphorus are the ones most apt to be in short supply naturally, and since some of the blue-green algae have nitrogen fixing capabilities, phosphorus has been in many cases the most important added nutrient in bringing about excessive growth.

There have been several man-made sources of the nutrients that bring about eutrophication. They include domestic, industrial, and agricultural wastes. Sewage has been an important source of nitrogen and phosphorus as well as organic matter. Detergents are important contributors of phosphates. Agricultural fertilizers and livestock and poultry wastes are also major sources. Cattle, horses, hogs, sheep, chickens, turkeys, and ducks produce more than a billion tons of solid wastes and nearly one-half billion tons of liquid wastes annually. Cattle, with a population nearly half that of the human population, produce nearly 20 times as much waste.

Wastes from slaughter houses and food processing plants often end up in the waterways. Boats discharge a variety of pollutants including sanitary wastes. Many million watercraft ply the navigable waters. Laws governing the discharge of sewage differ among the states, and the laws in existence have been often of negligible effectiveness.

Therefore, several points of attack are required to solve the problems. Better sewage treatment to remove nitrogen and phosphorus and more effective disposal of the organic material as sludge are needed on a large scale. Control of industrial and agricultural wastes would be able to mitigate the problems. As phosphate-containing detergents have been a major contributor of phosphorus, the elimination of phosphates from detergents would go far toward retarding eutrophication. Because food and other agricultural products come from the land, the return of agricultural wastes to the land would complete their cycle. More emphasis has been needed on research directed toward that end.

Several large bodies of inland water in the world are noted for their algal development due to eutrophication over a period of many years. These include Lake Zoar in Connecticut, Lake Sebasticook in Maine, the Madison Lakes in Wisconsin, Lake Erie, the Detroit Lakes in Minnesota, Green Lake and Lake Washington in the state of Washington, and Klamath Lake in Oregon.

There have been many examples of lakes that are in an early stage of their natural life history yet are in danger of eutrophication from man-made pollution. Lake Tahoe, nestled 6,225 feet high in the Sierra Nevada Mountains of California and Nevada, is at present one of the clearest lakes in the world. The lake is 21.6 miles long and 12 miles wide. The bottom is 1,645 feet beneath the surface at the lake's deepest point, with an average depth of 990 feet. The waters of Lake Tahoe do not, as yet, are able to support dense aquatic growth nor are they appreciably enriched. Blue-green and filamentous algae and other types that make objectionable surface growth are now found near the shoreline, but their presence is not critical because of the low nutrient content. Phosphorus concentrations have reached critical levels, but nitrogen levels have been stil low and this is believed to be the limiting factor in the further development of algal growth. However, additional residential and recreational development on the perimeter of the lake and further waste disposal in the lake may be having serious consequences.

13

Ground Water Pollution

INTRODUCTION

An exhaustive study of urban water supply system in developing countries revealed that at least 60% of the pollution is still dependent on underground sources of drinking water, especially in outer city areas and distant villages. This very important source of water is now polluted from seepage pits, refuse dumps, septic tanks, barnyard manures, transport accidents, and with diverse agricultural, chemical or biological pollutants. Otherwise important sources of groundwater pollution include sewage and soluble salts. The widespread practice of dumping raw sewage in shallow soakpits has made apprehension of pollution of ground water in many cities. It attributes in the rise of cholera, hepatitis, dysentry and other water-borne diseases, to the pollution of groundwater especially in the zones where the water table is high. The most common complaint is susceptibility to worm-infection.

In the industrial areas of Punjab, *e.g.*, Ambala, Ludhiana, Sonepat, etc., where bicycles and woollen garments are manufactured, significantly high concentration of nickel, iron, copper, chromium and cyanide have been reported in groundwater samples.

Control of groundwater pollution needs accurate information on the distance between aquifer and the ground, the volume of the

ground water body and the structure of the underlying stratum, and also on the physico-chemical and biological characteristic of the pollutants. Appropriate control measures could be taken into consideration after monotoring the samples of underground water at different depths of the suspected areas.

The groundwater systems have been affected in a completely different manner by the input of various contaminants. As there is no euphotic zone and, consequently, no food chain as such, many of the materials tend to accumulate in these systems for long periods of time. In addition, if groundwater use has been faster than replacement, these systems may become drastically depleted. The two major consequences of groundwater mismanagement have been therefore, contamination and depletion.

1. Contamination

In areas utilizing groundwater, the water is located in aquifers at various depths. Some aquifers have been shallow and the first to be used. Others are deeper and are tapped only when the shallower aquifers become contaminated or depleted. Water drawn up from an aquifer has been used and discarded as either household or industrial wastewater. If the wastewater is released into *lagoons* (a common method of industrial waste disposal) or cesspools, it will slowly percolate back into the aquifer under the influence of gravity. In addition, pesticides, fertilizers, and de-icing compounds also tend to enter the water table through percolation. As water trickles through the sediment overlying the water table, it has been purified to some degree. Most of the bacteria as well as the suspended organics and most of the pesticides get filtered out or absorbed by the sediment within approximately 30 feet (ft) of the source of input. Soluble substances like dissolved metals and nutrients pass unchanged into the water table. The nutrients are converted from their organic to their inorganic form by bacterial action. In the inorganic form they are usable by plants but are, in the aquifer, out of the euphotic zone and therefore spatially unavailable to plants for use in metabolic processes. Consequently, large reservoirs of unused nitrate and

phosphate tend to build up. The dangers of nitrate contamination have been established.

Excessive phosphorus, in any form, is not having any apparent deleterious physiological effects. In addition to the possible harmful effects of nitrate on infants, it is to be noted that both phosphorus and nitrogen do pose harmful environmental effects.

These effects arise because recharge has been generally into shallow aquifers. Because of lateral flow, nutrients eventually reach the euphotic zone by flowing into streams, lakes, and so on. As this takes place the nutrient levels of surface waters increase and eutrophication follows.

The contamination of aquifers by nonnative heavy metals was illustrated in 1972 in Bomay. In that year, water from wells was found to have chromium and cadmium levels hundreds of times above accepted levels. The source of these metals was traced to a local metal-plating plant that discharged industrial waste water into leaching basins. Additional investigations revealed a body of contaminated groundwater 4200 ft long and 1000 ft wide moving southward, via lateral flow, into previously uncontaminated wells. The discovery of the contamination of these shallow wells necessitated the tapping of deeper aquifers, fortunately uncontaminated to supply this area with safe drinking water.

A potential source of contamination has been the disposal of waste materials by injection wells. In many countries the laws restricting the disposal of liquid wastes into surface waters forced industries to seek other means of waste disposal. Consequently, in many portions of the country, disposal of materials like oil-well brine and industrial waste is accomplished by injection into deep, permeable rock structures.

This system of liquid waste disposal may cause unforeseen environmental hazards. At the present time little is known of the fluid movements and physical and biological changes that occur in deep aquifers under the process of injection. An example of not

considering the physical and chemical implications of injecting waste substances occurred in Erie, Pennsylvania when a paper-mill injection well, operating at a depth of 1600 ft, exploded. spewing 50,000 gallons/day of a sulfite liquor waste into Lake Erie. The well blew up when the injection tubing got corroded and the build up of pressure within the aquifer forced the waste liquid back up the well casing to the surface.

One of the most widely known cases of unexpected problems associated with subsurface injection had been the apparent stimulation of earthquakes between 1962 and 1966 during the operation of injection wells for the disposal of noxious chemical wastes at the Rockv Mountain Arsenal near Denver, Colorado. It was postulated that the waste fluids may have acted to permit slippage of rock masses by lubricating faults deep in the earth's crust.

Less well known but of greater potential hazard was the prediction that these substances would tend to migrate and thus contaminate aquifers as far east as Kansas and Nebraska (U.S.A.).

Alarmed at the increasing popularity of this disposal method, the many environmentalists opposed injection disposal without strict controls and clear demonstration that such disposal will not harm present or potential subsurface water supplies.

2. Depletion

As an area develops and population increases, the volume of wastewater increases, resulting in an incsease in the deleterious substances leaching into local aquifers. Eventually, the water will get contaminated and reach a state where it will be either unsafe or unaesthetic for use. It then becomes necessary to exploit a new aquifer at a deeper level than the one initially used and contaminated.

The practice of using, contaminating, and exploiting new aquifers cannot continue indefinitely. Eventually even the deeper aquifers become endangered, either by depletion or contamination. Although recharge of water has been not directly into the deeper

aquifer, contamination is possible since water is drawn from the deeper aquifer, used, and released as wastewater to the superficial aquifer. Consequently, a situation arises where water has been withdrawn but not returned to the same water table. This will bring about a reduction in the hydrological head of the deeper aquifer. As the hydrological head gets reduced, an increased vertical flow from the shallower aquifer will occur and water will tend to leave this aquifer at a rate faster than it is replaced by rainfall. This causes the contaminated water to move downward at an increasing rate.

In addition to contaminating the deeper aquifer, this increase in vertical flow will tend to deplete the upper aquifer. This is undesirable because it has been this aquifer which supplies the majority of water to streams, lakes, and rivers. In many areas the reduction in flow or the actual drying up of streams and lakes has been a visual indicator of a lowered water table.

Another consequence of excessive groundwater depletion may be subsidence (the sinking of the land surface to fill the void created by removal of the groundwater). The most common form of subsidence takes place in regions where the subsurface rock strata are interspersed with layers of loose, fine-textured sand and silt. As water could be removed from the pore spaces this material becomes compacted. In these areas the land surface may sink at rates of ½ inch to 2 ft/year.

A less common type of subsidence takes place in areas of limestone bedrock, in which water has formed cracks and caverns. Removal of the water from these underground reservoirs may allow the upper soil layers to enter the void and form cavities nearer to the surface. In these cases a minor surface shock can trigger a sudden cave-in.

Once it has been obvious that the deeper aquifers have been becoming contaminated, most communities begin a sewage-treatment program. The most common type of treatment known as secondary treatment. These systems are incapable of sufficiently

purifying wastewater for reuse, and so it must be disposed of either by pumping the partially treated effluent into rivers, bays, or the ocean or, if the facility is not located near a body of water, by lagooning.

If the treated effluent (from secondary treatment) gets released into a surface-water system, it will increase the BOD and also lead to eutrophication of that system. Discharging rather than recharging this water will also lower the water table, reduce stream flow, and, in coastal areas, encourage saltwater intrusion. Disposal of this material into lagoons or leaching basins will cause contamination of the aquifers (in a manner similar to cesspool recharge).

14

Bacterial and Parasite Pollution

INTRODUCTION

Bacterial contamination has been the most common water-borne disease hazard in the world. In many parts of the world both bacterial and other types of organisms have been ever-present threats. Typhoid fever and cholera periodically cause widespread illness and death. Various forms of gastroenteritis have been common. The protozoan *Entamoeba hystolitica* causes a type of dysentery that is often serious. Parasitic worms of various kinds are transmitted by water. Eggs of tapeworms and roundworms are found in sewage. Pollution of streams by domestic and wild animals may be a source of contamination. Along the Nile River in Africa, *Schistosoma*—a blood fluke—attacks people who come in contact with the water, especially the farmers who work in the irrigation-flooded fields. The eggs find their way into the kidneys and get discharged in the urine, after which they quickly develop into larvae that must find an alternate host, the water snail, to continue their life cycle. Several species of flukes, all of which are parasitic worms, cause serious diseases in different parts of the world.

An early method of determining the microbial purity of water had been to take a reading of its "keeping power." Water that was

free of bacteria could be stored for a long time, while contaminated water would tend to develop growths aud undergo visible changes. Increasingly widespread use of the microscope made it possible for establishing standards based on the numbers and kinds of organisms and organic debris that could be found in the water. Later, bacteriological tests got devised that were reliable and specific for the detection and identification of microorganisms.

INDICATORS OF EXCREMENT

Examination of water for each of the various kinds of pathogenic microorganisms has been slow, unwieldly, and costly. Therefore, bacteriological tests have been used to detect the presence of bacteria that are presumed to be of fecal origin and thus indicative of sewage contamination. When indications of fecal pollution are found, the water is considered to be potentially dangerous to health. The bacteria used as indicators have been described as *coliform* organisms, a group which includes diverse microorganisms, the best known of which have been strains of *Escherichia coli* and *Enterobactor aerogenes*, which are usually, though not always, of fecal origin. Coliforms could also be nonfecal types that thrive on organic material of vegetable origin.

Coliform bacteria could be removed by chlorination and filtration. Even when this is done, it is important to identify coliform bacteria in the raw water because their presence has been an indication of sewage pollution. Sewage may carry other bacteria that have been resistant to treatment in addition to viruses, organic matter, and chemical contaminants having uncertain, but potentially dangerous, effects on human health.

Standards for bacterial contamination differ among the various states and countries of the world.

There has been some risk in relying on the level of coliform contamination. The standards have been criticized as arbitrary. Most of the outbreaks have been attributed to accidents or to breakdowns in sanitation systems. A puzzling case was an outbreak of

gastroenteritis in Riverside, California, in 1965 when several thousand people got attacked within a few days by an infection of *Salmonella typhimurium*. The city's water supply was heavily polluted with the organisms, which must have gained entry during a short period. The source of the pollution was never found, or if found, was not reported. How such a large break could take place in a municipal water system remains a mystery.

15

Marine Pollution

INTRODUCTION

Everything that is carried away by rivers ultimately goes in seas. This gives rise to pollution by sewage, grabage, agricultural waste, fungicides, pesticides and heavy metals (*e.g.*, mercury) ; by discharge of oils and petroleum products ; and by dumping of radioactive waste into sea. The large amount of plastic waste dumped into the oceans has already threataned marine life. The plastic packing material is being dumped into the sea by commercial fleets. About 15% of the world's 280 species of sea birds are known to ingest plastic. Once in the stomach, plastic brings about a multitude of gastrointestinal problems. It reduces the animals hunger sensation and causes the development of ulcers in stomach and intestines. For plastic containing PCB, a chemical known to cause eggshell thining and its tissue damage, the effect on marine animals would be more damaging than ordinary plastic. Radioactive waste includes Sr^{90}, Cs^{137}, Pu^{239} and Pu^{240}. However, radioactive waste in ocean water totals to about 0.1% of concentration, and consequently does not pose much serious problem of pollution.

The pollutant gets dispersed by turbulence and ocean currents, or concentrated in the food chain components or in bottom sediments by various physico-chemical processes including adsorption, precipitation and accumulation. Bioaccumulation in the food chain components causes loss of species diversity, thereby unstabilising and simplifying the otherwise complex and stable ecosystem.

Most probably the most serious pollutant has been the oil, especially when afloat on the sea. Much of the oil and petroleum products are shipped by sea and any spill as a consequence of accidents, deliberate discharge of oil-polluted waste water, etc., can cause serious pollution problem. A seminar on "Marine Pollution" reported that in one year Bombay Port Authority collected more than 90,000 litres of waste oil from "Indra Dock" Basin alone (The Times of India, August 6, 1984). Oil in the ocean has been a serious threat to marine life including fish, birds, invertebrate and algae. Birds are frequent victims. Some ornithologists estimate that 50,000 to 250,000 birds get killed each year by the effect of oil. The oil soaks into their feathers, displacing the air normally lodged there and interfering with bouyancy and maintenance of a constant body temperature. Once birds get oiled, they seldom survive despite efforts to clean them. Cancer-inducing effect of oil pollution because of accumulation of hydrocarbon benzpyrene through food chain in human beings has also been suggested.

Sometimes the spills themselves are not very harmful to marine life, but the detergents employed to clean up the spill may prove extremely harmful. An interesting example supporting this has been high martality of marine life caused by the use of large amounts of toxic detergents to clean up the oil slick resulted from notorious Torrey Canyon disaster, exemplies this.

Monitoring and research in the area of marine pollution control have been fast developing activities in India. The studies on marine environment have been undertaken since mid-seventies by the various institutions in the country.

Every major port in India is creating a separate anti-pollution cell to control oil and other pollutions. Pollution in areas beyond the control of the ports would be taken care or by organisations like Coastal Guards. The International Marine Pollution Convention (MARPOL) stipulates that ships and ports should have certain facilities for reducing pollution. Steps have been taken by part authorities to introduce anti-pollutant measures in ports.

16

Human Waste Pollution

INTRODUCTION

Part of the living process has been to get rid of unwanted material. Otherwise organisms die of the toxins in their own waste. The biological process for ridding the body of wastes has been termed as *excretion* and occurs in some manner in all living creatures. Man and other vertebrates have several mechanisms for excretion. In man, the skin eliminates unwanted water, salts, and carbon dioxide ; the lungs expel carbon dioxide and water ; the liver, an important detoxifying organ, drains bile constituents into the alimentary canal ; the kidneys purify the blood and expel the wastes through the urinary system ; the intestinal tract gets rid of salts, minerals, fats, and indigestable material rejected as unsuitable for food or metabolic processes.

The excreta of the alimentary canal are termed as *feces*. They consist primarily of intestinal bacteria, which comprise the most bulky portion of human waste. The urine, of which about 1½ liters get excreted daily by a human adult, has been mostly water with dissolved nitrogenous wastes and salts. The urine also carries away foreign substances like drugs and other toxins.

DISPOSAL OF THE WASTES OF LIFE

When no more than 100,000 people populated the earth during the Ice Age, human excretion was no particular problem. It was accomplished by walking to the woods or the rocks and leaving the waste for disposal by coprophagous (dung-eating) organisms. Nature has several answers to the population problem. One effect of overcongestion is that the waste products eventually become so concentrated that many of the organisms die out from toxins, disease, or abnormal behavior. Sometimes they become cannibalistic or otherwise self-destructive. Some of them may survive by escaping to less congested areas. Civilization, with its concentration of humans living in cities, aggravates the problem of waste disposal beyond that which can be solved by natural means.

Two of the most important discoveries in the history of sanitation had been the invention of toilet paper and the water closet. The latter evolved in a primitive form while papyrus had been solely an instrument for communicating knowledge.

The people of the Harappan culture of the Indus Valley, circa 2500 B.C., had been perhaps the first to become experts in sanitation. Household water supplies, bathing facilities, and drainage systems were widespread. There were bathrooms with waterproof floors. Latrines with seats got built into some houses. There were sloping or stepped channels through the wall to either a pottery receptable or brick drain outside. At Mohen-jo-Daro each house was having a drain which ran into a central sewer system under the street which fed into cesspools. Manhole covers of brick were installed to allow for repair and cleaning. The citizens of the ancient Indus would no doubt look with disfavor on the chaotic sanitation in some parts of the modern world where sewage is sluiced along gutters and open sewers to spread vermin, bacteria, and pestilence.

The ancient cities of Sumer and Babylon seem to have had similar hygienic devices. In the city of Akhetaton in Egypt, built

during the Eighteenth Dynasty (1580-1340 B.C.), upper-class houses were equipped with bathrooms, drains, braziers, and stands for holding jars of drinking and washing water. Sanitation facilities in Crete (about 2000 B.C.) were highly developed. Large pits were constructed and lined with stone into which sewage was drained. The palaces were provided with running water by means of tile pipes. The early Greeks also made advances in hygiene, but it remained for the engineering genius of the Romans to produce the greatest achievements in public waste disposal in the ancient world.

Excavations of Pompeii reveal that there had been a central distributing system that delivered water to each house. Nearlv every house in Rome had a cistern, water faucets, and pipes of lead or terra cotta. The *cloacae* of ancient Rome were sewers laid out to drain the marshy grounds between the hills of the city. The most important one, known as the *Cloaca Maxima*, drained the Forum and dated from about the sixth century B.C. The *Cloaca Maxima* would today be called a "combined sewer" inasmuch as it received both sewage and surface drainage water. It discharged into the Tiber. It was 10½ feet wide, 14 feet high, arched in stone, and paved with lava in polygonal blocks. It was so well constructed that it still serves the city. Cities in the provinces also had drainage systems with flush latrines, sewage storage tanks, and sanitary treatment works. Public latrines as they appeared 1,500 years ago may still be seen in the provincial cities and at Timgad in northern Africa. It cannot be regarded, however, that every residence in such well-engineered cities got connected to a sewer.

The use of waste for productive purposes has been an ancient solution to the disposal problem. Animal dung has been used as fertilizer for thousands of years. Homer, who portrayed Greek society of about 800 B.C., related how the good King Laertes laid manure on the land with his own hands. Two ancient writers on agriculture, Cato (184 B.C.) and Varro (116-27 B.C.), advocated manuring of crops. In the Orient human dung has been used as fertilizer for centuries and has been today a convenient answer to

the dual problems of disposal and food production. The practice has been not aesthetically or economically satisfactory in an industrial society, although dried sludge is produced by some modern sewage treatment plants as a by-product and sold as horticultural fertilizer.

It was not until 1596 that the water closet, first used by the people of the Indus Valley about 4,000 years earlier, was reinvented in its modern form by the Englishman Sir John Harington, godson of Queen Elizabeth I. It was one of the few advances in hygiene made before the nineteenth century. The rediscovery of the water closet was an important development, for that at time even the finest palaces had nothing more than open privies due to the lack of sewage facilities. Even so, it was slow to be adopted. Harington discussed his invention in one of the first examples of satire in the English language in a work entitled *A New Discourse on a State Subject, Called the Metamorphosis of Ajax*. The Queen liked the new invention and is said to have had it installed at Richmond Palace.

As civilization progressed, the privy and such bathroom facilities as ingenuity could manage began to make living conditions tolerable. But the congestion of people in industrialized areas changed all this. Descriptions of the cities depict a grim picture of conditions during the middle of the nineteenth century.

Typical of the situation in all big cities was the condition of the tenements of Glasgow where there were no drains or even any privies. Dung was left lying in the courtyards next to houses. In another Scottish city there were no private lavatories and only two or three public privies located in the better sections of the city. Sanitation was no better in other European cities and in some it was worse. In those days it had been the practice of the citizens to use chamber pots for excreta, and when the pots were filled, to empty the contents out the window and into the street below with a shout, "Gardez l' eau!" for the benefit of the nimble-footed. In London, the sewage of a population of nearly 3 million people was

collected in a single, huge cesspit in the center of the city. During the hot summer months the stench was nearly beyond human endurance.

The Great Stench of London that occurred during the summer of 1858 almost brought the deliberations of Parliament to a halt. Steps were taken to overcome the noxious fumes by hanging blankets saturated with chloride of lime over the windows. The courts declared a recess and travelers avoided the city. Surprisingly, there was little increase in disease and people came to realize that diseases were not transmitted through odors and that filth, in itself, did not cause disease. This knowledge, however, was dangerous for it caused the citizenry to ignore the formidable potentiality for disease and epidemics in the slovenly practices.

The terrible epidemic of Asiatic cholera that struck London in 1854 could have been prevented if it had been known that the disease is caused by a germ carried from feces to underground drinking water. John Snow, a London doctor, showed in a classic study that 500 victims who died within ten days had all used the same community water pump. (It is interesting to note that Snow made his study 28 years before Robert Koch, the German scientist-doctor, discovered cholera germs in water contaminated with sewage.) The subject of sanitation became the most popular topic of news and conversation. Corrective measures were taken. As a consequence, the development of drains and sewer systems was probably the most important advance of the Industrial Revolution in the latter half of the nineteenth century.

DEVELOPMENT OF MODERN WATER SEWER SYSTEMS

Many of the early systems were of dubious value. Aesthetic reasons, perhaps more than hygienic reasons, stimulated the construction of sanitary facilities. Cesspools were dug everywhere and many of them were prolific breeders of contamination because of seepage into nearby wells. As a result, typhoid fever and cholera epidemics were rampant. In time, the methods were improved.

London installed a sewer system in 1865 and many English cities followed the example. Similar advances were made by American cities. By 1900 more than 3,500 United States patents had been granted for improvements on Harington's "Ajax" and nearly 900 patents had been issued for sewage devices.

According to an inventory for 1982, municipal sewage systems in the United States served 165 million people. This still left about 55 million people without sewage facilities. Of those now provided with sewers, 36 million people are served by sewers that are designed to handle both human waste and surface drainage. These are known, technically, as *combined sewers* (see Fig. 16.1). They often present formidable problems when storm drainage necessitates the run-off of raw sewage. According to a 1987 survey published by the Federal Water Pollution Control Administration of the U.S. Department of Interior, 25 per cent of the cities with combined sewage systems had no treatment plant.

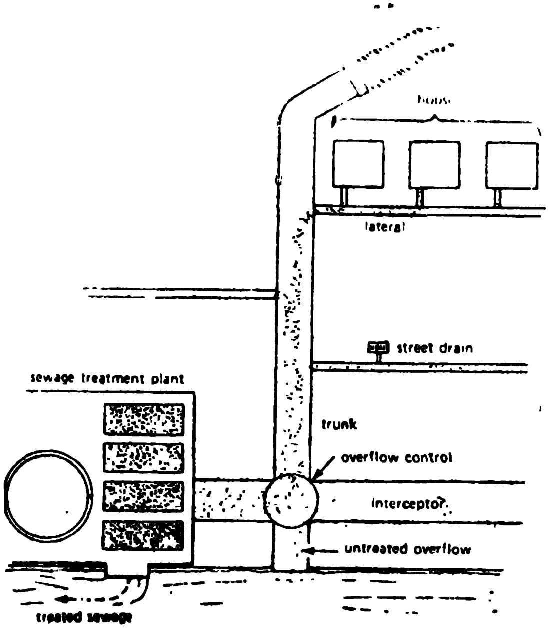


Fig. 16.1. Combined sewer system.

In communities that are served by sewage systems, 60 per cent of the waste receives primary and secondary treatments (removal of solids and bacterial breakdown). However, 30 per cent of the waste from sewered communities gets only primary treatment (removal of heavier solid material) and 10 per cent of the waste is disposed of as raw, untreated sewage. Of the combined sewers (those carrying both storm and waste water) in the United States, the Department of the Interior reported that 22 per cent of the cities provided no treatment, 42 per cent only primary treatment, while 35 per cent provided both primary and secondary treatment. One per cent of the cities are still having some type of third-stage treatment.

The composition of sewage has been complex, and it differs depending upon the sources, the type of treatment or lack of it, and whether there is an admixture of storm drainage with industrial waste. Unfortunately, analyses and inventory of waste constituents, a necessary step for rational planning of water pollution control, have been thoroughly done in only a few cases. Inorganic constituents, like the salts of sodium, potassium, calcium, magnesium, and ammonium, together with chloride, nitrate, bicarbonate, sulfate. and phosphate ions are commonly found in abundance. Organic chemical compounds in waste have been poorly investigated, with the exception of some extensive work on pesticides and detergents and, to a more limited extent, on organic acids and phenols. A large number of organic and inorganic substances have been identified in domestic sewage. Many of them are probably breakdown products of excreta More information on the constituents derived from human waste as well as industrial waste and surface drainage into the sewer sinks is urgently needed.

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Agricultural Pollution

INTRODUCTION

Very broadly, agricultural pollution is caused by refuse of any form from agricultural operations of any kind. In common usuage the term agriculture refuse generally includes the following types of waste :

(*i*) Manure and other wastes from farms and the operation of feedlots or poultry houses.
(*ii*) Slaughterhouse wastes.
(*iii*) Fertilizer runoff from cropland.
(*iv*) Harvest wastes.
(*v*) Pesticides that escape in the atmosphere or into the water supply.
(*vi*) Salt and silt drained from irrigated land or eroded land.

Pollutants from Feedlots

Scientists believe that liquid wastes from the feedlot industry may seriously contaminate the water table. Ammonia volatilizes from liquid feedlot wastes, but because of its ready solubility in water, it returns to nearby lakes and streams. Feedlot wastes have high biological oxygen demands ; their nutrients upset natural ecological communities and nourish plant growth ; water purification plants in communities downstream are taxed with increased burdens

of sludges and have more difficulties in eliminating objectionable tastes and odors from the water. Feedlot runoffs may also add disease causing organisms to the water.

Fertilizer Runoff

Farmers distribute fertilizers extensively on croplands, pastures, and orchards. These fertilizers are important to high-yield agriculture. It is assumed that one-third of the country's annual production of food and natural fiber is attributable to fertilizers. Their extensive use, however, creates some problems. Some (but much less than half) of the phosphates entering water come from fertilizer runoff.

Nitrates are especially susceptible to runoff with each rainfall, and they enter groundwater. Where they are extensively used, they appear in well water.

Harvest Wastes

These include the straw left over from harvesting wheat and other cereal grains, corn stalks, the remains of annual plants raised as vegetables, and similar materials. Straw is a commodity used in agriculture as bedding material, as mulch, and as an absorbant for liquid wastes in barns. (It has little food value for livestock). Straw has been used as an absorbing agent in cleaning oil spills from surfaces and shore areas. Much of the wastes from harvests are shredded and worked into the topsoil, where the material eventually decays and provides some enrichment for the soil. Unless this procedure is carefully managed, these wastes may harbor pests. Where the law allows open burning, some harvest wastes are burned. Due to the oil embargo of 1973, there has been increased interest in using fermentation to convert feedlot and harvest wastes into methane or methanol.

Pesticides in Runoff

Pesticides in soil are carried into lakes and streams in the dissolved state, as well as on soil particles in the runoff. It is believed

that the pollution of ground water by pesticides has been found to be more widespread than commonly has been realised but the concentrations (less than 1 microgram per litre or less than 1 ppb) are very low. Serious poisonings of well water by pesticides usually occur by accident during the handling of the chemicals.

Soil Erosion

Sediments—(soil and mineral particles) get washed into streams by storms. The amount of soil erosion occurring in the world today may be two or three times what it was before man's intervention in nature. Some 3½ billion metric tons of sediments are washed into tributary streams each year, about one-fourth of them eventually being transported into the sea. At least half of this sediment is coming from agricultural lands, with water erosion being a dominant problem. Eroded materials can also be contributed by urban, industrial, and highway construction sites and by road banks, and urban areas can be major sediment sources.

Sediments have been both a blessing and a curse to agriculture. They have added to the fertility of the soil where deposited, as in the Nile River Valley in Egypt, and they have settled in and destroyed irrigation systems such as those of the ancient Sumerians. Sediment can settle on trout spawning beds and suffocate the eggs. It can clog gills of adult fish. It interferes with domestic and industrial uses of water and produces extra expenses for clarification of the water. It can lead to reduced dissolved oxygen levels and thereby adversely affect aquatic life. It affects the recreational values of lakes, reservoirs, and streams and shortens the life of farm ponds by producing an increased rate of filling through siltation.

In recent years it has been realized that sediments carry many inorganic and organic materials with them, often adsorbed to the surfaces of silt particles. In particular, phosphorus adsorbed on silt and carried to the bottom of lakes and rivers may play an important role in eutrophication, and many water-insoluble pesticides (such as the chlorinated hydrocarbons) are carried into waterways by sediment. Control of soil erosion consequently looms as one of

the most important present-day concerns in the control of environmental pollution.

Control methods exist that can cut erosion rates down to 10 to 50% of current rates without affecting agricultural productivity. These methods act to reduce the kinetic energy of raindrops and flowing water and keep the soil particles in place. The presence of vegetation, either living or dead, reduces erosion. If the soil is covered with grasses or trees, the vegetation will intercept raindrops and prevent them from imparting their energy to soil particles. Much of the rainfall will be absorbed in the ground instead of flowing over the surface of the land and this, too, leads to reduced erosion. It is well-known that in periods of heavy rainfall, flooding will not occur on forest lands but will occur on nearby land which has been developed commercially.

Control methods are especially desirable on sloping lands since the amount of erosion increases rapidly with increasing slope. In addition to planting suitable vegetation, the land may be shaped to reduce the erosion. Even in ancient times good agricultural practice included the building of terraces that followed the contour of the land and forced downward-flowing water to encounter a series of flat pieces of land. Terraces can take a long time to build and can make it difficult to apply mechanized agricultural techniques, straighter and thus easier to farm. Erosion can also be reduced by growing different crops in alternate strips ("strip cropping"), using broad, gently sloping waterways covered with a thick carpet of grass, and by preventing overgrazing of grassland by livestock, which destroys the vegetative cover.

With erosion is a related problem. Strong winds can carry soil particles into the air and thus produce the air pollution problems associated with airborne particulate matter. Many fields filled up with sand dunes and many homesteads were covered up. These problems are alleviated by a good vegetative cover that can be maintained on the land. Most serious wind erosion is likely to

accompany periods of drought where maintenance of vegetative cover is difficult. Residue from the previous crop left on the surface of the soil will reduce soil loss from wind erosion. The growing of hedges and other windbreaks (junipers, ponderosa pines, etc.) has also helped in the deserts.

Plant Residues

Plant residues from crops and orchards can constitute environmental pollution when they harbor plant diseases and pests or when they are burned and emit smoke and hydrocarbons, since both situations correspond to an unfavorable alteration of man's environment. Agricultural burning is a fairly important air pollution problem. It is estimated to be responsible for :

8.3 per cent of carbon monoxide emissions.
8.5 per cent of particulate matter emissions.
5.3 per cent of hydrocarbon emissions.
1.5 per cent of nitrogen oxide emissions.

Agricultural refuse are burned. Much of this burning is for sanitation purposes since plant debris can carry diseases or pests to succeeding crops. Burning of grass residue is the only practical method of controlling blind seed disease by the Oregon grass seed industry. Agricultural burning and the resulting air pollution problems are likely to continue until better methods of controlling the plant diseases are available.

Plant debris can be used as a mulch ; *e.g.*, it can be spread over the ground under orchard trees. Mulching on a large scale can be effected on croplands by leaving residue from the previous crop on the soil surface. Mulching is known to reduce wind and water erosion and it sometimes (but not always) leads to improved crop yields. Plant residues are also used to some extent for other purposes, such as bedding for poultry and livestock or in the manufacture of corrugated cartons.

The logging debris are left in forests annually. This debris can act as a reservoir for tree disease and insects, just as elms killed by

Dutch elm disease and oaks killed by oak wilt can transmit disease to healthy trees. Controlled burning is the only feasible disposal method at present. It causes air pollution problems, and has interfered with recreational activities and airport operations. Unburned debris from logging operations is a very serious fire hazard, which is known to cause larger-than-average forest fires.

Agricultural Chemicals

In recent years there has been an increased use of agricultural chemicals, notably pesticides and fertilizers. These chemicals have been effective in controlling diseases and pests that affect crops, livestock, and even humans, and they have enabled farmers to secure high crop yields at relatively low cost. They contribute to air and water pollution, however, and have adverse effects on fish, wildlife, and, upon occasion, human beings.

The availability and low price of commercial fertilizers has led to rapid increases in their usage. Problems can arise from excessive application rates since the fertilizers can be transported into groundwater by leaching or into waterways by natural drainage and storm runoff. Nitrates are of special concern but they generally find their way into waterways from feedlots, not from excessive or improperly timed fertilizer use. Nitrates in drinking water can cause methemoglobinemia in babies ("blue babies") because in an infant's stomach the nitrate (NO_3^-) is converted into nitrate (NO_2^-), which acts on the blood hemoglobin to form methemoglobin. The same process can occur in the stomach of ruminants so that livestock can also be affected by nitrate poisoning.

Plant nutrients also contribute to eutrophication. Phosphorus is often implicated in algal blooms in waterways. Phosphates have a great affinity for soil and are generally carried into waterways adsorbed to sediment, in a state unavailable for plant growth.

There are some alternatives to the use of inorganic fertilizers on agricultural crops. One is the return to the methods of years

gone by, including use of organic fertilizers (such as animal wastes) and crop rotation (such as planting legume crops occasionally to increase the nitrogen in the soil). Another possibility is that the government might find it necessary to institute controls on agricultural chemical usage.

Miscellaneous Agricultural Pollution

There are several other types of pollution that occur in agricultural areas.

Animal Disease Agents. Infectious agents transmitted by air, water, and soil can affect livestock, poultry, and humans.

Dead Animals. The disposal of dead animals is another problem. Poultry meat decomposes readily and produces objectionable odors, while the feathers are rather inert and stable. Incineration can be difficult and can produce air pollution. Disposing of carcasses by delivering them to rendering plants is probably the best solution. Sometimes, though dead animals are thrown in old wells, where they may lead to groundwater pollution.

Rural Domestic Wastes. The domestic wastes in rural areas must also be considered. Generally the waste waters are disposed of in the ground through the use of pit privies, cesspools, or septic tanks. Sometimes the absorptive capacity of the soil is inadequate for proper disposal. The main concern is to prevent contamination of groundwater supplies or at least to prevent contamination of wells from which drinking water is obtained.

Food Processing Wastes. Industry in agricultural areas can also couse serious pollution. Of particular note would be industries closely associated with agriculture, such as the food processing industry. These industries can produce both air pollution (such as by cotton gins and alfalfa mills) and water pollution).

Salinity of Irrigation Water. Inorganic salts present in the soils and geologic materials of arid regions can move into waterways and be deposited on farms that use irrigated water, and the salinity of the soil can build up unless effective drainage is provided for.

Conclusion

In conclusion, it should be noted that the greatest agricultural pollution problem at present is probably soil erosion by water and wind, especially since many other agricultural pollutants (such as pesticides and phosphates) are transported by sediment.

The animal waste problem is already important in some areas such as near large feedlots, and could be a problem of overwhelming importance if no animal wastes were returned to the soil.

It should be recognized that our agricultural problems are aggravated by our eating habits. Agricultural problems would be lessened if we were vegetarians since the use of grains and grasses and other plants for animal food, which is then used for human food, is a rather inefficient process. Putting a given acreage into soybeans for human food would yield over 10 times as much protein as putting into corn to be fed to livestock and eventually converted into meat protein. Many countries obtain little food from animal sources ; meat consumption in China and India is very close to zero.

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Industrial Pollution

INTRODUCTION

The contribution of the chemical industry to human welfare is evident in the wide range of chemicals used in drugs, cosmetics, plastics, synthetic fibers, paints, cleansing agents, and many other kinds of consumer products. Unfortunately, most of the chemicals end up in the environment. A high proportion is sluiced down the sewers and ultimately into rivers, lakes, and oceans. Many of the chemicals are highly toxic to living organisms. Some of them find their way into the food chain, disrupting or impairing the natural biotic cycle, threatening populations of organisms with extinction, and jeopardizing the quality of man's food supply. Natural waters from some rivers and lakes are becoming unfit for domestic use and some streams have become biologically barren.

The dependence of present-day society on chemical technology is almost beyond comprehension. Synthetic chemicals of every conceivable kind, from medicines to miniskirts, are part of our everyday life. Nearly two million chemical compounds are known and several thousand new ones are discovered each year. More than 9,000 synthetic organic compounds are used commercially, with 300 to 500 new ones being added annually.

When the explorer Thor Heyerdahl sailed his papyrus raft westward across the Atlantic in 1969, he was dismayed at the

abundance of flotsam that he encountered. In some areas the floating debris carried foul-smelling oily material. About twenty years earlier, he had sailed across the Pacific in a similar craft, the *Kon Tiki*, and had experienced a relatively unpolluted Pacific Ocean. During the intervening period, relentless pollution with garbage, sewage, industrial wastes, and similar debris had established a markedly deteriorating trend in the quality of the oceans.

Oceans are not having the rapid turnover that takes place in rivers, springs, and lakes. The oceans have been more stable and maintain their chemical composition over periods of thousands of years. Injurious chemicals can build up in concentration over long periods of time unless they are decomposed. Poisonous metals have been indestructible. A classic example has been the disastrous result of discharging industrial effluent containing mercury, such as that which occurred in Minamata Bay of Japan. Even some synthetic organic chemicals are having remarkable stability, as, for example, DDT and many of the plastics.

Under the anaerobic conditions of silt and mud, chemical substances may be relatively free of oxidation and other chemical degradation as well as resistant to bacterial decomposition. But it cannot be regarded that chemical pollutants will remain indefinitely at the point of deposition. Some of the pollutants may become buried in the sediment near the coastline where they can be consumed by microorganisms and mud-inhabiting worms. Thus, chemicals and their degradation products are taken up in the food chain and passed from one species of organism to others that prey upon them. Some of the organisms may be carried by ocean currents ; fish and other organisms may travel under their own power for great distances.

A large number of organic and inorganic substances have been identified in domestic sewage. Materials that are known to be potentially serious pollutants include sundry chemicals from domestic disposal, such as from household cleaners, medicines, and chemicals in food wastes ; a wide variety of industrial chemical

wastes, including petroleum products, phenols, solvents, chemical intermediates, metallic wastes, and by-products which may be highly toxic to living organisms; pesticides from agricultural use or industrial waste disposal; and radioactive chemicals, some of which have toxic properties lasting for thousands of years and whose fate in the food chain is largely speculative, though they are among the most toxic substances known.

Sometimes contamination of the underground water supply, as well as surface waters, comes from unsuspected sources, as in cold climates where roads are commonly salted during the coldest winter months to lower the freezing point of water and prevent the formation of a hard, slippery coating of ice. In porous soils, large amounts of salt leach into and through the soil where it can make water unusable.

Industry is the largest single user of water, accounting for 50 per cent of the daily water requirement. Treatment of industrial waste waters gets complicated by the presence of a wide variety of both inorganic and synthetic organic pollutants, many of which are not readily susceptible to biodegradation. Solvents, oils, plastics, plasticizers, metallic wastes, suspended solids, phenols, and various chemical derivatives of manufacturing processes are apt to be difficult to identify and impossible to remove without more advanced technology than we now possess. Some of the substances have been known to be highly toxic to living organisms but have been of unknown effect as environmental pollutants.

One method used to dispose of industrial toxins has been to inject the waste water deep underground. A large petrochemical plant pumps wastes containing phenolic compounds into a well 6,000 feet deep and wastes containing a class of chemicals called nitriles into a separate well 7,000 feet deep. Disposal of toxic substances deep underground needs careful study of the possibility of irretrievably contaminating the underground water supplies because subsurface water may move for considerable distances underground. Another dannage of underground disposal has been that the pressure might

cause slippage of deep layers of rock, resulting in earthquakes. A series of earth tremors in the Denver area were apparently associated with deep underground disposal of wastes.

Pulp and paper has been the fifth largest industry and is the third highest in the total industrial use of water. Strenuous efforts are being made to reduce the amount of water used per ton of product. The rate of reuse has been now about 216 per cent, among the highest in industry. Pollution stems from suspended matter and large amounts of dissolved organic substances, the removal of which has been generally difficult and expensive. More than 7,000 gallons of water are needed for each ton of wood pulp produced. Treatment costs come to about 30 to 36 million dollars a year. This would increase to about one billion dollors if the entire industry were to achieve 85 per cent B.O.D. (biochemical oxygen demand) reduction and nearly complete removal of suspended solids.

The iron and steel industries have been large users of water. By the nature of their operations, they have critical requirements for specialized pollution control facilities. The amount of water needed usually ranges from 20,000 to 50,000 gallons per ton of steel produced, although one mill, by using advanced water conservation methods, has reduced its requirement to less than 2,000 gallons per ton. Water reuse in the industry is generally about 40 per cent of the total throughput. Effluents may run at rates of 10 to 25,000 gallons per minute. The processes of a large steel mill may generate as many as 100 distinct kinds of discharges requiring 5 to 10 separate waste flow systems, two-thirds of which involve chemical, sedimentation, or filter treatment. The principal pollutants have been scale, oils and greases, and miscellaneous chemical wastes.

Some industries recycle a large proportion of their water needs, especially water used for cooling. One large petrochemical plant uses 1.5 billion gallons of water per day of which only 10 per cent is new water. The industry average is probably 1 gallon of new water in each 3 gallons of water used. There has been increasing

interest on the part of industry to reuse its water, not only for reasons of expense and pollution control but also because there is an increasingly limited supply of available water.

INDUSTRIAL WATER WASTES

The importance of industrial water wastes can be realised from Table 18.1, which lists the estimated volumes, BOD, and suspended solids before treatment for industries. The table also includes, for comparison, the corresponding figures for the sewered population of 120 million persons assuming daily per capita production of 0.36 m^3 waste water, 75 g BOD, and 91 g suspended solids. A detailed inventory of industrial wastes would, of course, have to include such important quantities as the amounts of toxic metals, refractory organic compounds, and other water pollutants.

Table 18.1. Estimated volume of untreated waste water and mass of BOD and suspended solids for industries and sewered population (of 120 million persons).

	Waste water (billion m^3)	*BOD (10^6 kg of O^2)*	*Suspended (10^6 kg)*
Primary metals	16.3	220	2130
Chemical	14.0	4400	860
Paper and allied products	7.2	2670	1360
Petroleum and coal	4.9	230	208
Food and kindred products	2.61	1950	3000
Transportation equipment	0.91	54	—
Rubber and plasticts	0.61	18	23
Machinery	0.57	27	23
Textile mill product	0.53	400	-
Electrical machinery	0.34	31	9
All other manufacturing	1.70	177	420
Total manufacturing	50	10,000	8200
Domestic (sewered)	20	3300	4000

In some areas with heavy industrial concentration industrial wastes are many times as great as domestic wastes.

1. Food and Kindred Products

Wastes produced by the food processing industry—meat and dairy products, beet sugar refining, brewing and distilling, canning, etc.—tend to be troublesome mainly due to their high content of putrescible (decomposable) organic matter, which can result in oxygen depletion and water supply impairment in much the same way as domestic sewage. The ment (cattle, hogs, poultry) processing wastes. come from stockyards, slaughterhouses, packing plants, and rendering plants and contain blood, fats, proteins, feathers, and other organic wastes. In many countries, these wastes are being, dumped into the rivers. The dairy industry produces organic wastes high in protein, fat, and lactose from milk and cheese processing. Whey from the production of cheese is an important BOD source in parts of states with an established cheese industry. The beet sugar refining industry produces wastes of high BOD content, including sugar and protein. Breweries and distilleries produce organic solids containing nitrogen and fermented starches from grain processing and alcohol distilling. The processing of food to produce canned or frozen products leads to enormous amounts of wet solid wastes. Food processing often involves some danger of infectious disease.

2. Textile Products

Textile mill wastes, generated by cooking the fibers and desizing the fabrics, have high BOD and are quite alkaline, requiring neutralization and other treatment. The wastes arise from impurities in the fiber and from the chemicals used in processing. The production of 1000 kg of wool leads typically to 1500 kg of impurities (wool fibers, sand, grease, burrs, etc.) and 300 to 600 kg of process chemicals, with a total of 200 to 250 kg BOD. Cotton processing leads to relatively less total BOD but the waste water may have 200 to 600 mg/BOD.

3. Paper and Allied Products

Paper and pulp mills, in addition to being notorious air polluters, produce a great amount of water pollution. The effluent, is a complex mixture of the chemicals used in the kraft process stray wood chips, bits of bark, cellulose fibert, and dissolved lignin (woody tissue carbohydrate). About 50% of the wood used as input is eventually discarded as waste material. Mill effluent tends to be deep brown in color and can thus interfere with aquatic photosynthesis. It also contains compounds toxic to fish such as methyl mercaptan and paper and wood pulp preservatives such as pentachlorophenol and sodium pentachlorophenate. Sulphite liquor is also toxic to shellfish.

4. Chemical Industry

A wide variety of water pollutants are produced by chemical plants manufacturing acids, bases, synthetic fabrics, pesticides, detergents, and many other compounds, organic and inorganic. Acid wastes result not only from acid manufacturing plants but also from almost all other chemical plants as well and are customarily neutralized to give a pH of at least 6. Wastes from DDT and rayon manufacturing are especially acidic because a large amount of sulfuric acid is used. The production of the herbicide 2,4-D leads to dichlorophenol in the water, and the effluent may contain 25 ppm dichlorophenol despite treatment that removes 95 to 98% of the compound. The waste waters of the phosphate industry contain elemental phosporus, fluorine, silica, and large amounts of suspended solids. In recent years mercury waster from chemical plants (as well as other types of factories) have caused great concern.

5. Petroleum Industry

Oil drilling wastes include drilling muds, saltwater brines pumped out of the well with the crude oil, and some oil as well. Oil refineries and petrochemical plants produce an astounding number of different pollutants. These include hydrocarbons, acids, alkalis, cyanides, numerous sodium salts, phenolic compounds.

numerous inorganic and organic sulphur compounds and halogenated and nitrogenated hydrocarbons. Many of these compounds cause detectable tastes and odors at concentrations in the ppb range : ethyl mercaptan at 0.00019 mg/l, isoamyl acetate at 0.0006 mg/l. hydrogen cyanide at 0.001 mg/l. etc. Others cause fish flesh to acquire adverse tastes at concentrations of less than 1 ppm ; *o* chlorophenol at 0.015 mg/l ethyl benzene at 0.25 mg/l, kerosine at 0.1 mg/l, etc.

6. Coal Industry

Coal mines lead to acid mine drainage, including typically 100 to 6000 ppm suifuric acid. Coal-preparation wastes from coal washeries contain very large amounts of suspended solids—coal, shale, clay, sandstone, etc.

7. Rubber and Plastics

Wastes from rubber production are having a high BOD, taste, and odor. Synthetic rubber is prepared from butadiene and styrene in a soap solution and coagulated with an acid-brine solution, and the wastes have some of all the materials uaed. Odors from rubber plants can give rise to unpalatable water for several hundred kilometers. Plastics manufacture are producing wastes with hydrocarbons and other organic compounds, as well as various reagents.

8. Metal Industries

Steel mills are producing water wastes from the coking of coal, the washing of blast furnace flue gases, and the pickling of the steel. These wastes are acidic and are having cyanogen, phenol, ore, coke, limestone, alkali, oils, mill scale, fine suspended solids. Larger mills may recover by-products but smaller mills do not find this economical and may simply neutralize the acidity with lime, which leads to a large volume of sludge. Other metal industries are facing similar problems and their wastes generally have the metal being produced or plated—chromium, lead, nickel, cadmium, zinc, copper, silver, etc.—as wall as acids, alkaline cleaners, grease, and oil.

9. Other Industries

Other industries are also producing a wide variety of water pollutants. Leather tannery wastes have high total solids, hardness, salt, sulphides, chromium, alkalinity, lime, and BOD. Polishing of optical glass produces red (from iron) wastes containing detergents and suspended solids that do not settle readily. Laundries have turbid wastes which are alkaline and have organic solids. Radio-active wastes result from nuclear power plants, fuel reprocessing plants, and hospitals and research laboratories using radioisotopes. Soft-drink bottling plants are also producing highly alkaline wastes with high BOD from the washing of bottles, which involves removal of cigarette butts, paper, and other debris left in the bottles by previous users.

19

General Aspects of Prevention and Control of Water Pollution

INTRODUCTION

Biodegradable pollutants alone cause the measure pollution load but there are also several kinds of ingradients such as heavy metals, refrectory chemical compounds and mineral oil which cannot be decomposed by mechanical or biological means. Inorganic fertilizers and various biocides are too responsible for contributing to this load. Efforts of control should, be undertaken to reduce the amounts of waste by reutilizing or recycling of their components. Control of water bodies and of organisms serving the porpose of water protection should get reinforced and carried out by all available means including legal enforcement under the provisions laid down in the Water (Prevention and Control of Pollution) Act, 1974 and the Environmental (Protection) Act, 1986. The various ways/techniques suggested for prevention and control of water pollution are briefed as follows :

1. Stabilization of Ecosystem

It is the most reliable way to control water pollution which involves reduction in waste input, harvesting and removal of biomass, trapping of nutrients, fish management and aeration. Various

physical and biological methods are followed to restore species diversification and eco-balance in the water body to prevent pollution.

2. **Reutilization and recycling of waste**

Various kinds of wastes like paper pulp, municipal and industrial effluents, sewage and thermal pollutants can be recycled to advantage. For example, urban waste could be recycled to generate cheaper fuel gas and electricity. One large size urban waste recycling plant is already existing at Okhla near New Delhi. The total gas generation from the plant is about 0.6 million cubic feet per day having a heat value of 700-800 BIU per cubic foot. A new technology of waste recycling and disposal has been introduced by a distillery in Gujarat. This technology would not only help the distillery to treat 450,000 litres of waste daily before letting the effluent into streams but also generate energy equivalent to that given by 10 tonnes of coal every day. The regulated use of thermonuclear reactions in controlled fusion reactors to produce cheap electricity as suggested by Eastlund and Gough (1969) could solve the problem of accumulation of waste in the twenty-first century.

3. **Removal of Pollutants**

The various physicochemical techniques used for removal of chemical biological or radiobiological pollutants have been adsorption, electrodialysis, ion exchange and reverse-osmosis. Of the various techniques, the reverse-osmosis technique is based on the removal of salts and other substances from water by forcing the later through a semipermeable membrane under a pressure that exceeds the osmotic pressure so that flow is in the reverse direction to the normal osmotic flow. In practice, this involves a porous membrane whose chemical nature has been such that it has a preferential attraction for solvent while repulsion for the solute. Reverse-osmosis has been commonly used to desalinate brackish water and also finds suitable, effective and economical method for the purification of water polluted by sewage effluents.

Techniques introduced by C.S.I.R. for the control of water pollution have been successfully used for the removal and reuse of pollutants from industrial effluents. Some of the achievements are described as follows :

(*a*) *Ammonia removal from the waste water of industry.* Ion-exchange technique using a weakly acidic cation exchanger based on methacrylic acid is employed to remove ammonia from waste water in the form of ammonium sulphate which can be reduced for the manufacture of fertilizer. The process has good application potential not only for pollution abatement, but also for the recovery of the pollutant in the form of useful salt.

(*b*) *Removal of mercury from chlor-alkali plants effluents.* Mercury thrown out from chlor-alkali plants gets removed and recovered by mercury-selective ion exchange resin.

(*c*) *Removal of phenolics.* Phenolics in waste water produced from industries such as pulp and paper mills, carbonization plants, petroleum refineries, tanning industries and resin manufacturing units are removed by the use of polymeric adsorbents.

(*d*) *Decolourization of water.* An electrolyte decomposition technique has been developed to decolourise the waste water from saree dyeing and printing industries around Jetpur in Gujarat.

(*e*) *Removal of sodium salts.* Reverse osmotic technique is used to recover sodium sulphate from rayon mill effluent. The technique is also used to recover water for reuse. Similarly, 70% of the protein and 80% of the lactose can be recovered from cheese whey by reverse osmosis ; which otherwise would cause a serious pollution problem.

20

Sewage Treatment

INTRODUCTION

The most common form of water pollution control consists of a system of sewers and waste water treatment plants. Waste water is collected by the sewer system and delivered to the waste treatment plant, where it is made "fit" for discharge back into the general water supply. The discovery of more pollutants is causing serious questions to be raised concerning the real meaning of the term "fit" as used above.

The methods used to treat sewage before it gets discharged into rivers, lakes, or the ocean are not excessively expensive. The procedures are regarded to be effective for the purpose of rendering the waste moderately safe insofar as its bacterial content is concerned. But the virus load and toxic chemical content of sewage discharges have not been as thoroughly evaluated.

The processes of treating municipal sewage have been broadly classified as *primary*, *secondary*, and *tertiary*. The particular process used in a given situation has been found to depend on the volume to be treated, the location of the outfall, the dilution factor, the potential hazard to users receiving the water, and in many cases, the cost of the project.

Primary Treatment Process

Primary treatment is a mechanical process which simply removes solids. Metal screens stop large solids ; sands and small stones settle in a grit chamber from which the water passes into sedimentation tank, where its rate of flow has been sharply reduced and small particles settle as a sludge. Scum at the top is removed. The quantities removed at this stage can be huge. Primary treatment is able to remove organic material responsible for 25–30% of the biological oxygen demand of the sewage. However, primary treatment is normally carried out in a series of steps :

1. *Screening.* Large floating objects could be removed by passing the waste water through screens. Some plants use a device called a comminutor, which screens and grinds the material. The shredded or ground material remains in the water to be removed later in a settling tank.

2. *Grit removal.* Sand, grit, cinders, and small stones are allowed to settle to the bottom of a girt chamber. It has been a very important step for cities that have combined storm and municipal sewage systems. The grit obtained in this process is disposed of by using it for land fill.

3. *Sediment removal.* Sewage, even after removal of grit, still has suspended solids. These will settle out if the speed of sewage flow gets reduced. This is accomplished in a sedimentation tank. The suspended solids settle out and the solid mass, called raw sludge, has been collected for disposal.

The primary treatment has been completed when the effluent, from which grit and sludge have been removed, has been treated with chlorine gas before discharge into a stream or river. Chlorine gas is added to destroy disease-causing bacteria. All of the steps in primary treatment of sewage are represented in Fig. 20.1.

Primary treatment removes about one-third of the BOD and suspended solids and a few per cent of the refractory (persistent)

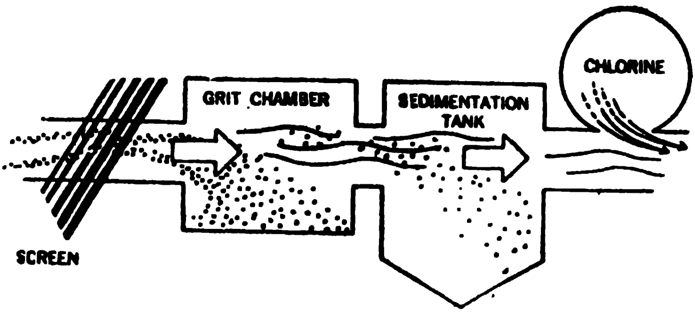

Fig. 20.1. Primary sewage treatment.

organic compounds and plant nutrients. It is obvious that today, when concentrations of pollutants are discussed in parts per million, simple primary treatment of sewage should be supplemented by further treatment methods.

The primary sludge is a burdensome problem because it is bulky and must be removed. It contains 94 to 99 per cent water. Usually the first step has been to remove as much of the water as possible. In some cases, the sludge has been dried in beds with some of the water being removed by filtration. The residue gets disposed of on land. Because the sludge itself can comprise a pollution problem, a better method has been to bring about microbial decomposition in *sludge digestion tanks* before drying. Sometimes sludge sedimentation and digestion occur in a partitioned structure called an *Imhoff tank*. The microbial action take place under anaerobic conditions, and because this proceeds slowly at low temperatures, the digestion tanks are usually heated to 80 to 90°F, at which temperatures the sludge decomposes in 20 to 30 days. The digested sludge will have been reduced to about one-third of its original volume and will be relatively inoffensive.

The other products of primary treatment have been gases and the fluid or clarified waste water. The gas has been mostly methane, which is usually burned as fuel to provide heat for the digesters and other equipment. The clarified waste water has highly objectionable

properties and in most cases has been put through a secondary treatment.

2. Secondary Treatment Process

Secondary treatment is essentially a biological process which is designed to remove most if not all remaining organic matter. Water leaving conventional secondary treatment facilities normally is down to a BOD of 10% or less of the initial value ; 95% of the original bacteria is removed, along with 10% of the phosphates and perhaps as much as 50% of total nitrogen. In the activated sludge process of secondary treatment, the incoming sewage is mixed with decomposer bacteria and air or oxygen. One of the hazards of this method has been that a toxic, industrial chemical may enter the sewage, kill the decomposer bacteria, and wreck the operation for weeks. The mixing of industrial wastes with town wastes at one treatment plant is thus a potentially costly and dangerous practice, needing constant monitoring. Aeration (mixing with air) may be done by spraying the water over filter beds or be sending it through large, rotating, multinozzled distributor pipes that also let the water trickle through multilayered filter beds. A modern filter bed has a layer of relatively large pieces of anthracite coal on top, then a layer of smaller granules of silica sand, and finally a bottom layer of small-grain, high-density garnet sand. This operation produces a sludge that must be disposed of. After treatment, the water may get chlorinated to kill disease-causing bacteria.

Sewage from about 40% of the population receives secondary as well as primary treatment. Two processes are currently available for secondary treatment : the tricking filter and activated sludge processes.

An efficiently operating activated sludge system is able to remove up to 90% of the suspended solids and BOD. A good trickling filter system has been capable of removing 80-85%, but in practice 75% is more common.

A trickling filter has been simply a bed of stones and gravel 3 to 10 feet deep, through which the sewage passes slowly. Bacteria

gather and multiply on the stones and gravel until they become numerous enough to consume most of the organic matter in the sewage. The water, after passing through the activated bed, trickles out through pipes in the bottom of the filter.

The trend in new secondary treatment plants in away from trickling filters and toward the activated sludge process. In this process, the rate of bacterial action is increased by bringing air and bacteria laden sludge into very intimate contact with the sewage, which has previously received primary treatment. The essentials of the process are illustrated in Fig. 20.2. Sewage, air, and activated sludge remain in contact for several hours in the aeration tank. During this time, the organic wastes are broken down by bacterial action.

A recent improvement in the process has been made by using pure oxygen instead of air. It has been known for a number of years that more bacteria could be supported in a smaller space with less pumping of air (oxygen) if pure oxygen were used. An economically competitive system using oxygen has only recently been developed. The system achieves 90% utilization of oxygen, compared to 5-10% in conventional systems. It has been called by some the most significant recent advance in sewage treatment.

The sewage flows from the aeration tank into another sedimentation tank, where solids could be removed. Chlorination completes the basic secondary treatment.

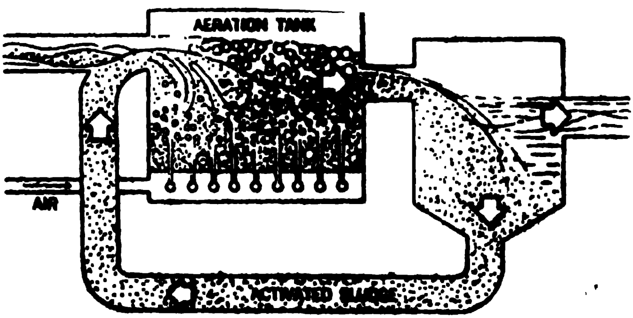

Fig. 20.2. Activated sludge process.

The sludge, which has the bacteria, can be used again by returning it to the aeration tank and mixing it with new sewage and air or pure oxygen.

A few of the treatment plants heat-dry the activated sludge, usually after some form of mechanical water removal, called *dewatering*, and sell the product as fertilizer. The process has been costly and there has been only a limited demand for the product. It is less expensive to incinerate the sludge in furnaces or to use it as landfill. Incineration sterilizes the sludge and reduces its volume. However, incineration is some having some disadvantages. It creates an air pollution problem and leaves an ash that must be disposed of. Still, disposing of a small amount of ash is easier than getting rid of a large amount of sludge.

The methods used for disposal of sludges have been usually those that are the least costly. Whether disposal on land or sea is selected depends on the proximity of the treatment plant to suitable disposal locations. Dewatered sludges are commonly used as landfill. Trucks, trains, barges, and pipelines are used for transporting the sludge. Liquid sludges have been disposed of either on land or in bodies of water. Liquid sludge is used to fertilize or condition agricultural land. However, problems of odor, water pollution, and stimulation of insect and algal growth, as well as other aspects of public health and aesthetic values, must be regarded.

3. Tertiary or Advanced Treatment Processes

Tertiary treatment is able to remove virtually all the remaining contaminants. Water leaving conventional secondary treatment still is having most of the original phosphates and nitrates, any persistent insecticides and herbicides, disease-causing bacteria, and viruses (if any), and perhaps a number of industrial, organic compounds. Waste water that is not subjected to tertiary treatment contains the nutrients on which algae thrive.

Primary and secondary sewage treatment lower the BOD of the water and eliminate harmful bacteria. They do not, however,

effectively remove other dissolved organic and inorganic compounds. If water is going to meet water quality standards of the federal government (some are now in effect and others are yet to be established), attention must be paid to these modern-day pollutants.

Thousands of waste treatment plants will be constructed or expanded in the future to meet the demands for pure water, and these plants will be built to meet the government's water quality standards. They will look and operate much differently from the plants built during the last 30 years.

During the last decade a wide variety of treatment steps beyond secondary have been considered, and some are now being incorporated into water treatment sequences on a trial basis. These advanced treatment techniques, under investigation, range from extensions of biological processes capable of removing nitrogen and phosphorus nutrients, to physico-chemical separation techniques such as adsorption, distillation, and reverse osmosis.

Most dissolved refractory organic compounds remain in water that has gone through primary and secondary treatment. These persistent compounds resist bacterial action. The effects of such compounds in water are not all known, but taste and odor problems, tainting of edible fish, and fish kills have been attributed to their presence.

It has been found possible to remove 70-80% of these compounds by passing the previously treated water through a bed of activated carbon. The organic compounds leave the water and are absorbed on the surface of the carbon. Most of the carbon now used is in granular form, but the use of a powdered form is being investigated. The powdered form needs less contact time but is more difficult to handle. Granular carbon could be reactivated for further use by heating it in multiple hearth furnaces. A loss of about 5% of the carbon is experienced during each reactivation.

When powdered carbon has been used, it is put directly into the water. The organics adsorb to the carbon, which is then removed

by using coagulating chemicals. The usefulness of the process depends upon the development of effective methods for regenerating the used powdered carbon for re-use.

The plant nutrient, phosphorus, could be removed from water by precipitation methods. This technique may be used as a separate step in waste water treatment. Two chemical approaches are commonly used : in one, lime (CaO) if added to make the water alkaline and to precipitate the phosphorus; and in the other approach, metallic hydroxides are added. In either case, are inorganic phosphorus (as phosphate) is precipitated as insoluble phosphate salts of such metal cations as Fe^{+3}, Al^{+3} or Ca^{+2}, and the organic phosphorus compounds are adsorbed onto the hydroxide floc (precipitate) formed by these same cations in alkaline solutions. The resulting sludge could be collected and treated to regenerate the precipitating agent.

Unfortunately, nitrates, the other basic plant nutrient, cannot be removed the same way as phosphates because most nitrates have been water-soluble. Biological methods are being sought as possible solutions to this problem.

The removal of inorganic salts has been a problem which must be dealt with in water treatment. Typically, a city doubles the initial concentration of salts in water by using it. A possible method for removing these salts from used water has been electrodialysis. Electricity and membranes have been used in this complicated process. The membrane used in usually made of some chemically treated plastic.

When this method is used, an electric current is allowed to pass through the water by means of two electrodes. The immersed electrodes are separated from each other by membranes. The ions in solution are attracted toward the electrodes, pass through the membranes, and leave cleaner water behind. The treated water is ready for re-use of further treatment. A typical cell used in this process is represented in Fig. 20.3.

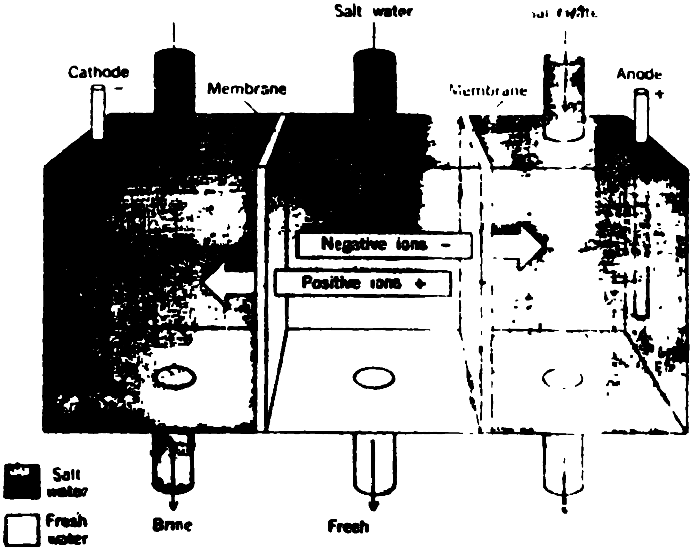

Fig. 20.3. Electrodialysis cell.

The electrodialysis method has two problems associated with it. Organic molecules cannot be removed by the process and tend to collect on the membranes and reduce the effectiveness of the cell. The second problem has been that of finding suitable disposal sites for the large amounts of brackish waste water produced. Because of the latter problem, the process could be limited to use in areas located near large bodies of salt water, where disposal has been possible.

A one-step electrodialysis treatment of water, with units now being tested, is able to reduce the total dissolved salt content by about 35% and allows a 92% recovery of water. A reduction of salt content by 35% is significant, because it represents an amount of dissolved salts nearly equal to that added by a typical city as a result of use. Thus, the salts added to sewage during use in a city can nearly all be removed before the sewage is returned to the general supply.

A process called osmosis takes place when two solutions of different concentration are separated from each other by a permeable

membrane. During this process, water molecules flow from the less concentrated solution through the membrane, into the more concentrated solution, until both concentrations are equal.

Reverse osmosis uses the above naturally-occurring process in reverse. Sufficient pressure can be exerted on the solution of higher concentration to overcome the tendency for water molecules to flow in, and instead cause them to flow out. This process amounts to removing water from the waste materials, rather than removing the waste materials from water.

One of the problems encountered with this equipment has been devising a suitable support for the large surfaces of the weak membrane so it can withstand the necessary pressure. Organic molecules tend to foul the membrane, but the problem has been not as serious with this technique as it has been in electrodialysis.

As it is the water and not the ions that pass through the membrane, reverse osmosis can reduce both organic and mineral salt content of the water. Pilot plant studies reveal a 90% reduction of total solids and a 75% recovery of water. The disposal of brackish water has been a problem with this method, as it has been with electrodialysis.

It must be noted that none of the processes discussed can complete the primary and secondary treatment methods. A series of treatment steps that might be applied, for example, has been as follows :

1. *Primary treatment.* Removes material that will settle or float.
2. *Secondary treatment.* Removes biologically decomposable impurities.
3. *Precipitation.* Removes phosphorus compounds and suspended solids.
4. *Adsorption.* Removes dissolved organics.
5. *Electrodialysis.* Returns dissolved salt concentration to the level present before use.

6. *Chlorination*. Removes disease-causing organisms.

A series of steps such as these does show promise for waste water treatment in the future.

Phosphates are the most difficult to remove from polluted water, yet their concentration must be reduced in areas where waste-waters cause lakes to undergo rapid eutrophication (*e.g.*, the Great Lakes area).

Instead of tertiary treatment, which actually disposes of nitrates and phosphates, the water from primary or secondary treatment in some areas gets channeled onto land where these constituents will act as fertilizers and the water will irrigate crops. Another approach is to let partly treated wastewater be released into beds of sands and gravel and returned to the aquifer.

A novel method of final sewage treatment is worked out by the Institute of Water Research, Michigan State University. Water from secondary treatment is piped to the first of three man-made lakes where the nitrates and phosphates in the water nourish aquatic plants. The plants, which have a nutritional value resembling that of alfalfa, may be harvested and fed to livestock. Then the water moves to a second lake where catach and bluegill bass grow. The surrounding grounds are landscaped for public recreation. The water is finally sprayed over nearby land to return it to the aquifer.

Sludge Removal

The better and larger a sewage treatment plant, the more sludge it produces, and handling this material can use up half the operating budget of a treatment plant. The sludge is dried and disinfected and is to be used to make fertilizer. Most of the large cities situated on the banks of ocean send concentrated wastes and sludges into the ocean through huge pipes.

Septic Tanks

In rural areas and rapidly developed urban communities municipal sewage systems usually are absent, and homeowners

install a septic tank. A septic tank is a waterproof, unventilated metal or concrete container placed underground to receive raw sewage Bacteria act on the organic components, reduce their volume, and convert them to gases, some liquids (particular organic acids), and inert solids that settle. Periodically the tank must be pumped clean. The gases diffuse into the soil, and the liquids flow into underground perforated pipes that spread out from the tank into a dispersal field. In ventilated soil, bacteria act further on organic matter.

Poorly located septic tanks endanger water supplies. Bacteria need time to act. If the dispersal field is too close to a well or a local aquifer, and if the soil is too sandy, waste liquids from the tank may enter the local water supply before bacterial decomposition gets completed.

STERILIZATION OF WATER OBTAINED FROM EFFLUENTS

With the increasing need to re-use domestic effluent as drinking water methods of sterilization are steadily assuming greater importance. Most of the effluent from sewage works has been discharged directly into rivers, and the discharge is carried out usually without sterilization. It is regarded that natural processes will be enough to destroy the bacteria still present in the sewage effluent after treatment. This assumption has been made more in hope than in certainty, and is very far from the truth. Rivers and lakes in many parts of the world have been so heavily polluted by bacteria that they are rightly considered dangerous for bathing. The essence of the problem has been of course, that the oxygen content of most waters has been too low to have an appreciable effect in reducing the bacterial count.

The principal bacteria and viruses present in purified sewage effluent released to rivers and thence to the sea have been as follows :

1. Dysenteric bacteria—Flexner's ***Bacillus dysenteriae, Shigella dysenteriae, Shigella paradysenteriae*** and ***Proteus vulgaris.***

2. Koch's bacillus—which causes tuberculosis.
3. *Vibrio cholerae*—which causes epidemic cholera. (This bacillus is no longer widely distributed in temperate areas.)
4. Typhoid fever bacilli—*Salmonella typhosa*, *Salmonella paratyphi*, Gartner's, Morgan's and Schottmuller's bacilli.
5. *Leptospira icterohaemorrhagiae*—which causes so called mud fever.
6. Polio virus.
7. Virus of infectious hepatitis.
8. Enteric cytopathogenic virus—which causes epidemic diarrhoea.
9. Adenovirus—which appears to cause eye and other infections.

In addition, it becomes possible for parasitic worms of many kinds to be discharged from purified sewage, but only if filtration has been poor. Provided the filter medium has been such that all particles greater than 20 microns in diameter are removed, there should be no danger of worm infestation. Amoebae which can make a variety of conditions including liver ulcers and intestinal haemorrhage have a diameter of 50 microns, and should also be removed by efficient filtration.

Bacteria, on the whole, have been very sensitive to sterilizing agents and are killed efficiently. Viruses, on the other hand, are much more resistant to oxidizing agents. The best methods of destroying viruses has been to allow a certain time between the collection and the purification of sewage effluent ; virtually all viruses are dead after about a week, because they are denatured by living microorganisms. Viruses can also be destroyed effectively by chemical flocculation, because a chemical reaction occurs between the virus protein and the metallic ions of coagulants. It is estimated that some 95-99 per cent of all viruses contained in a sample of sewage effluent could be destroyed in this way. In 'purified' water, viruses can survive for a long time.

It helps to explain why the spread of poliomyelitis often seems to be completely irrational. It does not affect appreciably people in underdeveloped countries who drink from heavily polluted rivers with high bacterial counts—but it *can* affect people in highly developed countries, where all the drinking water has been carefully purified and sterilized. The reason has been that in the polluted rivers the poliovirus is soon destroyed by microorganisms, while in developed countries careful filtration and sterilization simply eliminate the virus destroyers but have no effect on the viruses. These have been so small that they can pass through any filter medium, and are inordinately resistant to chlorine, ozone and other bactericidal agents. Modern sewage treatment processes, where crude sewage has been stored for a time prior to treatment, have been now much more effective in eliminating viruses.

Bactericidal Agents

The main methods of sterilizing water have been the following:

(*a*) The use of chlorine and its derivatives such as hypochlorites ;

(*b*) Ozone dosing ;

(*c*) Ultraviolet ray irradiation ;

(*d*) Electrolytic methods.

(*a*) *Chlorine and its derivatives.* For the sterilization of water either chlorine gas or one of the two salts sodium hypochlorite [$NaClO$] or calcium hypochlorite [$Ca(ClO)_2$] have been used. Chlorine, even in small concentration, effectively kills most bacteria, mainly because it destroys the enzymes needed by the microbes to survive. Enough chlorine has been normally added so that some free chlorine remains in the water after two hours of contact. This free chlorine—even in the most minute concentration—has been readily detected by the use of potassium iodide and a special indicator.

For slow sterilization a slightly acid medium has been preferred, together with intimate contact between water and chlorine for

at least two hours. If the temperature of the water has been less than about 10°C an excess of chlorine compensates for a slower reaction rate.

For rapid sterilization an excess of chlorine has been used in the water and allowed to destroy bacteria and other harmful organic matter for a period of about ten minutes. At the end of that time the excess chlorine gets neutralized by the addition of either sulphur dioxide, sodium sulphite or sodium thiosulphate.

As an alternative, ammonia could be added to the water, which converts excess chlorine into the chloramines—NH_2Cl, $NHCl_2$ and NCl_3. These chloramines have been quite odourless and have no specific taste, and they are bactericides in their own right. The bactericidal power has been, however, rather poorer than that of chlorine on its own.

For large plants, chlorine dosing has been effectively carried out with the gas itself. The main drawback has been that very strict control is essential ; even concentrations as low as 40 parts per million of free chlorine in the atmosphere have been highly dangerous. For smaller plants hypochlorites have been much easier to handle ; they can be dissolved or suspended in water prior to dosing.

Viruses like those of poliomyelitis and infectious hepatitis need quite high cuncentrations of chlorine for destruction—in excess of 0.4 mg/litre for 30 minutes or more. Koch's bacillus has been even more resistant and needs at least 1 mg/litre for an hour to ensure destruction. The remaining bacteria have been, however, easily destroyed at very low concentration. Chlorine has been not too effective in destroying larger organisms ; amoebae, for example, need more than 10 mg/litre for an hour for destruction. But as amoebae are having a relatively large diameter, they could be removed easily by good filtration practice.

(*b*) *The use of ozone.* Ozone is having the chemical formula O_3 and is made by passing air through a field of 'silent' electric discharge. Ozone cannot be stored because it disintegrates spon-

taneously ; it must, therefore, be produced on site from air. There have been several commercial ozonizers on the market designed to operate at about 12,000 V, obtained by means of a standard step-up transformer. The air entering the ozonizer must be perfectly dry to avoid the formation of nitric acid, which would destroy the electrodes. The ozonized air is then bubbled through water. It is best to use a good power agitator to ensure good distribution.

When ozone is used for water sterilization, an excess of ozone must be present for about five minutes where the temperature has been in excess of 10°C and for about ten minutes for temperatures below 10°C. Excess ozone could be easily detected by the use of potassium iodide/starch papers. When used correctly, ozone has been regarded to be more effective than chlorine for sterilization. The main difficulty with ozone is that it has been only sparingly soluble in water, and therefore effective dispersion has been vital to ensure that there is good contact between the ozone and the bacterial and virus matter to be destroyed.

(c) *Sterilization by ultraviolet rays.* The maximum bactericidal action of ultraviolet rays is when the wavelength of the rays has been in the vicinity of 260 nm. Ultraviolet light is commonly produced by a mercury vapour lamp. This method of sterilization has been only commercially viable when relatively small quantities of water are to be treated. The water must be very clean, otherwise some of the ultraviolet rays have been absorbed and thus rendered inactive. In general a 25 watt U/V lamp can be used for sterilization about 2000 litres of water per hour. The water has been led past the lamp at a depth of about 150 mm.

(d) *Sterilization by electrolysis.* Two techniques have been used. In the first, the anode is of silver and the cathode of either carbon or stainless steel. The electrodes must always be kept where the water is naturally turbulent. On the passage of an electric current, silver ions get released in solution, and these have a marked bactericidal effect. The quantity of silver needed for adequate sterilization has

been minute—normally of the order of 1 gram of silver to 20 m^3 of water. Faraday's laws apply to the electrolysis of silver which means that 108 g of silver are liberated by the passage of 96,500 coulombs (1 coulomb equals 1 ampere second).

Hence a current of 1 amp flowing for 1 hour liberates $108 \times 3600/96{,}500$ g of silver$=4$ g of silver, or enough to sterilize about 80 m^3 of water per hour. The silver, in the form of its ions, reacts with most bacteria to form a slime which can be filtered off. The method has been not as effective as chlorine or ozone dosing, and viruses have been much more resistant to silver sterilization than are bacteria.

The second method has been involving the addition of salt (NaCl) to the water ; the passage of an electric current produces free chlorine ions, which kill micro-organisms in the usual way. The passage of one Faraday (96,500 coulombs) of electricity produces 35.45 g of chlorine, and therefore an electrolytic cell which uses a current of 1 amp produces 1.35 g of chlorine per hour.

REUSE OF WASTE WATER

Many of the molecules of water that travel down the rivers in densely populated areas pass through the human physiological system several times—possibly 10 to 40 different bodies—before reaching the ocean. Even if the drinking water has been treated to kill most of the bacteria, we are repelled by the thought of drinking in the afternoon the molecules that were flushed into the sewer by our upstream neighbors in the morning. Yet that is literally what many people who live along the waterways are doing. The rivers have been used as repositories for vast quantities of domestic and industrial waste products having an unknown fate and largely unknown biological effects.

Some use is made of waste water from sewage plants for irrigation, mainly for nonfood crops and golf courses, but in some countries, untreated or poorly treated waste is used for vegetable farming. Along part of the southern coast, pumping of well water

for the burgeoning population has lowered the natural water table to the extent that underground intrusion of sea water is a serious threat to the water supply. When the underground water has been removed by pumping, the pressure is reduced and seawater fills the void by seeping into the area through underground strata of sand. Treated sewage waste water got pumped underground experimentally to replenish the natural water supply and create an artificial barrier against seawater intrustion.

Treated waste water is fed into several lakes that are used for recreational purposes. Treatment involves running the secondary waste water into an oxidation pond and then into percolation beds from which the lakes are fed by underground flow. There have been problems of eutrophication. Excessive aquatic growth causes oxygen deficiencies and subsequent fish kills. Even so, the project is considered generally successful. Similar plans for using treated waste for recreational purposes have been in progress. Though no public health problems have been detected, the need remains for careful study of chemical contaminants and their potential hazard to vacationers, sportsmen, and wildlife.

It cannot be assumed that tertiary treatment would render the water safe for drinking even if the effluent were free of pathogenic bacteria. Waste water may contain viruses as well as high concentrations of nitrates, phosphates, and other mineral salts. Organic degradation products of detergents and other domestic and industrial synthetic chemicals of largely unknown composition and biological activity may be present. The only place where waste water from sewage treatment is recycled directly into the drinking water is at Windhoek, South Africa, where treated sewage effluent normally makes up 14 per cent of the water supply, increasing in 40 per cent during the winter. South Africa is desperately short of water sources ; most cities are unwilling to bear the expense of extensive tertiary treatment or to run the risks the undetermined hazards that remain. Methods of advanced treatment that will permit large-scale reuse of waste water for domestic use have not yet been developed.

We can effectively cope with nearly all the water-borne bacterial diseases by conventional methods of treating supplies of domestic water. Sedimentation, filtration, chlorination, or combinations of treatments are generally reliable in providing drinking water that is potable and bacteriologically safe. Pathogenic viruses, however, present a more difficult problem.

The only one of the enterovirus diseases that has been proved to be water-borne has been infectious hepatitis, a dangerous liver disease that is incapacitating and sometimes fatal. The disease has been prevalent in many parts of the world. The spread of infectious hepatitis, as well as other viral diseases, by the reuse of treated waste water has been an eventuality that must be thoroughly explored before widespread reuse of processed sewage waste can be contemplated with confidence. Evidence indicates that the chlorination of secondary effluent in accordance with current practices does not remove or inactivate all of the viruses. It has been possible to filter out some viruses by adsorption on activated carbon, but the viruses are readily released and remain infectious. Removal by adsorption on precipitates has been also under study. Irradiation by gamma rays from radioactive isotopes can kill viruses as well as bacteria, but the effectiveness of disinfectants such as high-level treatment with chlorine or other disinfectants requires further research. Many of the reaction products of such chemicals acting on the organic materials also remain to be determined.

The renovation of waste water to a quality that would allow its reuse for a variety of purposes has been a major objective of current research projects. Some industrial users can tolerate more impurities than agricultural, recreational, or domestic users. Needed improvements include removal or inactivation of viruses, removal of salts or their dilution to lower the salt content to acceptable levels, continuous monitoring for a wide variety of chemical pollutants, and probably the development of ways to remove toxic substances.

Water usage is about 25 per cent of the fresh water supply that is now economically available from all sources. It is estimated

that we could provide 600 billion gallons per day out of a total run-off of 1,200 billion gallons. But there would still be serious shortages in some areas, especially in the drier sections of the west. As the demand for water increases and the price goes up, increasingly costly methods for the recovery of waste water become more feasible.

The problem is twofold : water in good supply and water of good quality. Future additional drinking water supplies may be obtained by several processes :

(*i*) Desalting of brackish and ocean waters, involving, however, high costs and transport problems.

(*ii*) Complete recycling-requiring, however, careful and extensive study of fail-safe systems for pollution control and removal of contaminants.

(*iii*) Dual supplies, involving one source for drinking, cooking, and bathing and another source for other domestic and horticultural uses. The latter would probably consume at least 80 per cent of the domestic water supply.

(*iv*) Greater economy in the use of water. For example, backyards and gardens are getting smaller in waterpoor areas of high population density.

Sooner or later, much of the sewage water will have to be recycled in order to meet the demand.

21

Treatment of Industrial Effluents

INTRODUCTION

The treatment of domestic sewage has been a comparatively simple procedure because it is virtually wholly organic in nature and very readily biodegradable. The only major difficulty which has arisen in the past has been with some of the many detergents which got disposed of with the domestic drainage water. In most countries there have been now laws which ban the domestic use of non-biodegradable detergents, and in consequence the sewage treatment problem they presented has been gradually disappearing.

The question of adequate treatment of industrial wastes has been far more difficult to solve. Industrial wastes have a far greater variety of impurities than domestic sewage. Many of these have been not only non-biodegradable but also they actively destroy the very bacteria that have been required for the sewage purification processes.

If industrial water has to be discharged into public sewers it becomes therefore, absolutely necessary that it be adequately purified beforehand. Often it does not pay a manufacturer to discharge all the waste water from a single process to the sewers ; instead he will partially purify the waste fluids from one process, and re-use the

water for other processes. Generally such a system makes him to recover certain by-products or other materials for re-use.

The problems involved have been found to vary considerably from one industry to another.

Food Manufacturing Industry

The industries concerned have been the rapid-gtowth industries of fruit and vegetable canning, packing, freezing and drying plants, etc. It has been estimated that in a country like USA annual production of dried vegetables alone accounts for 20 million tonnes of water—used in vast quantities for washing, cooking and conveying purposes.

The food industries have been typically seasonal, and tend to produce their largest quantities of waste liquors in summer, when the levels of rivers have been at their lowest. Dairies which produce milk, cheese and butter, discharge wash water and other wastes. By-products like skim milk, butter milk, whey and dirty milk recovered to be used as animal food-stuffs, but, generally speaking, the purification of effluents with a heavy lactose content requires complicated plant to carry out hot anaerobic fermentation. The costs involved have been for most companies, prohibitively high. Effluents from some food factories have been sprayed over agricultural land, and this can be advantageous ; many of the waste materials have been broken down naturally to give valuable fertilizers. However, this method of disposal of organic waste matter has to be carried out under strict farming control, as the wrong kind of organic effluent can be able to kill of certain plants.

Factories which are able to process edible oils and fats generally operate large scale extraction plants. Their effluents, unless properly treated, are having a high protein, fat and sugar content with a very high biological oxygen demand (BOD) value.

In the majority of fermentation industries and in yeast factories 'lagooning' has been successfully used. In breweries, waste water has been coming mainly from the washing and cooling circuits ;

only a small proportion of the effluent consists of heavily polluted liquids from presses and filters. Sugar mills, flour mills and starch factories have been facing similar problems. Abattoirs discharge water having a high content of suspended organic solids and fats ; the high BOD of this effluent has been a function of the blood and other materials suspended in it. Good filtration practice is able to reduce the figure considerably and at the same time produces useful by-products for animal feeding and fertilizer production.

Treatment of Food Trade Effluents

Screening has been used to remove larges solid impurities, and the plant may have to be equipped with a shredder, as for example in an abattoir.

Oils and fats could be eliminated by the use of flotation tanks in which these substances could be removed from the top in the form of emulsions. In the case of edible oils, effluents are first acidified.

Flocculation is done often after the pH gets altered by addition of acids or bases. This is the practice in dairies where proteins are to be eliminated.

As the effluents from food factories have been almost totally organic, further purification of effluents is then done by processes which have been similar to those used for the cleansing of domestic sewage, including aerobic and anaerobic bacterial purification, use of activated sludge, and so on.

Pulp and Paper Industries

Effluents from these processes are having both organic and inorganic matter. The pH has been found to vary widely and the effluents have been often strongly coloured. Flotation processes have been used to recover fibre during manufacture ; the effluent is supersaturated with air and passed to an open tank where suspended particles rise to the surface. Filter presses or vacuum and mechanical filters have been used to recover the fibres. The pH has to be modified to encourage other suspended substances to coagulate. Flocculation is done in settling tanks which is followed by sludge

extraction. Where the effluent has a high BOD, activated sludge treatment is used. It normally becomes necessary to add nutritive agents which are rich in bound phosphorus and nitrogen, to permit an adequate bacterial build-up.

Iron and Steel Industry

Due to the large quantities required for steel production, it has become commercially essential to re-cycle most of the water used. Water finds use mainly in cooling, gas scrubbing, removal of impurities and sludge, and granulation. For efficient re-cycling water has to be treated as it leaves each separate process. This is mainly done in thickeners designed to reduce overall water losses and to produce a highly concentrated sludge—often having in excess of 500 g of solid matter per litre.

Water used for washing blast furnace or converter gases could be purified in scraper type settling and thickening tanks. The tank depth could be as much as 6.5 to 8 5 m, to get maximum sludge concentration. Mechanical flocculation by sludge recirculation as well as chemical flocculation has been sometimes necessary due to the characteristics of the suspended particles. Additional drying in a vacuum filter or by centrifuge has been generally of advantage. Slag granulation water has been always re-cycled after cooling. clarifying and filtration. Rolling-mill water, laden with dross and scale, could be purified in tangential roughing tanks and scraper bridge rectangular settling tanks, with pressure filters at the final stage. Oil could be removed in the settling tanks by natural flotation. Pickling workshops discharge acid effluents with a high concentration of ferrous sulphate. The spent pickling liquors could be neutralized with calcium hydroxide or calcium carbonate, using automatic adjustment of pH. Dissolved iron could be removed by injection of air, which oxidizes the ferrous salts. The final sludge is having a mixture of calcium sulphate and ferric hydroxides, which could be filtered off and dried.

Mechanical and Electrical Engineering Industries

The principal sources of polluting effluents have been surface treatment processes. Although they have been not large in overall volume they could not be discharged into public sewers because they may be :

(*a*) Acid, *e.g.*, spent pickling liquors ;
(*b*) Poisonous, *e g.*, cyanides, chromates, etc, ;
(*c*) Have reducing properties, *e.g.*, ferrous salts.

Various electroplating and pickling processes need the use of concentrated baths and rinsing tanks. Closed circuit re-cycling of concentrated baths employing ion-exchange agents has virtually eliminated the need to discharge such materials to waste. Re-cycling has been now widely used for bonderizing baths and hydrochloric acid sheet pickling baths.

Methods of Purifying Remaining Liquids

Waters having cyanides have been treated with chlorine or ozone after addition of sodium hydroxide to render them alkaline. This effectively oxidizes cyanides. Chromates in solution could be reduced by means of sulphur dioxide in acid conditions. Other acid effluents has been then mixed with the treated cyanide and chromate solutions, and the mixture passed into a large tank where calcium hydroxide has been added. The sludge has been allowed to settle out and could be removed by rotary filters and filter presses. Plant can be made completely automatic so that the liquid which leaves it has a neutral pH of precisely 7 and is having neither oxidizing nor reducing properties.

If any of the effluents are having dissolved metals, these could be removed almost completely by using ion-exchange techniques. These have been expensive to operate, but they do reduce the danger of pollution by such poisonous metals as copper, lead, mercury and zinc virtually to zero.

Emulsified oils—particularly from machine shops—have been also a nuisance. Waters containing these have been first of all

acidified to break up the emulsion, and then passed into a flotation tank for flocculation and settling.

Chemical Industry

Of all manufacturing industries, the chemical industry—in this context including oil, fertilizer and other concerns—has been contributing most to the pollution of water. The problems have been arising from the very considerable variety of materials produced, and the fact that separation of many of these products from waste liquors needs specialized treatment in almost every case. In addition, a very high proportion of the waste liquors and solids produced by chemical works has been frankly poisonous. Often inadequate precautions have been taken in the disposal of very poisonous wastes. It has happened, for example, that cyanide drums have been dumped on public ground. The main methods of treatment of effluent liquors have been the following :

(*a*) In the case of acidic or basic solutions which are emanating from such processes as acid manufacture, production of caustic soda, nitrates or explosives, neutralization must be done especially using constant automatic monitoring of the pH value of liquids to get released.

(*b*) Dyes constitute a major source of contamination of effluents, especially when they get mixed with detergents and organic fluids ; similarly, many chemical processes have been producing effluents having phenols, nitrites, aldehydes and alcohols. These effluents have to be treated separately by oxidation or biochemical processes which have been found appropriate for inactivating the impurities in question. They cannot and must not be bulked—often the impurities present in one type of waste liquor interfere with adequate treatment of another. As an example, bacteria needed for the degradation of, say, textile fibres, will be killed rapidly by phenol. Some organic impurities may require to be oxidized, while others will have to be reduced.

(*c*) If it has been possible to flocculate impurities these could be removed by standard settling and thickening techniques. The sludge could be filtered off and dried.

(*d*) Trace quantities of obnoxious dissolved materials can generally be removed by ion-exchange processes. This especially applies to dissolved metals like mercury, beryllium and lead, which have been toxic and generally very harmful to all forms of life if released into rivers.

By and large, there have been few problems of effluent purification in the chemical industry which cannot easily be solved by proper application of present-day knowledge; yet the chemical industry has been still responsible for widespread pollution of our environment. The reason, has been noted and emphasized, is that existing laws in most countries are either not strict enough or not enforced sufficiently.

Toxic Solid Waste

Toxic solid waste from chemical works often includes the sludge removed from liquids. If these wastes could be indiscriminately dumped on public tips, toxic materials would get leached out and would ultimately reach watercourses. Even the smallest amounts of toxic impurities released in this way can have devastating effects, Recent evidence published on the concentration of mercury in the tissues of marine organisms and fish such as the tuna has been a very good case in point.

Many toxic solid wastes could be eliminated by tipping into disused mine shafts. It has been absolutely essential that, before this has been carried out a careful and thorough check has been made that the rock from which every shaft has been constructed has been free from fissures and completely watertight. In general, if a shaft is perfectly dry inside, it has been reasonable to assume that this is the case and unless there is a major earth movement, a subsequent hydraulic connection has been unlikely.

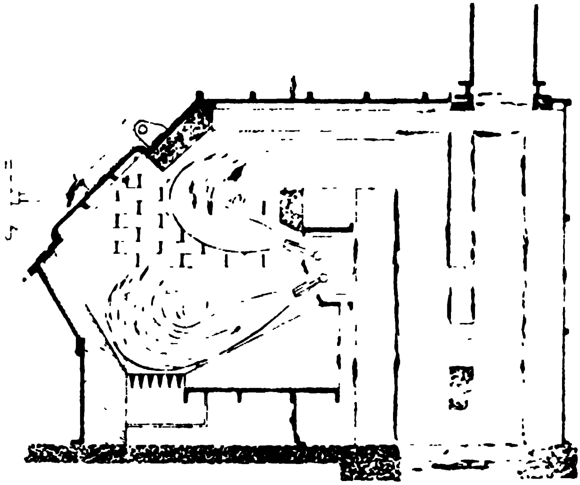

Fig. 21.1. Incinerator for sludges from effluent plants.

If the toxic solid wastes have been organic in nature, incineration has been the best method to dispose of them.

Toxic wastes could also be also discharged at sea. If the point of discharge has been outside territorial waters there is no obligation to obtain any authority from anyone to discharge. Nowadays sea pollution has been a matter of international concern, as many organisms concentrate certain poisonous components, so that eventually the poisonous substances again reach land in the tissues of polluted fish. This is a field in which international legislation has be.n now long overdue.

Atomic Energy Industry

The nuclear power industry, due to its inception and by its very nature, has had to give careful consideration to the decontamination and purification of its effluents. This is, as it must be, one of the main concerns of any 'modern' industry.

In the uranium extraction plant, grinding and washing of the ore causes acid effluents, rich in ferric iron, which must be neutralized and clarified. This problem has been encountered in the

majority of mines whatever the nature of the ore. At nuclear research centres, plutonium preparation plants, and at nuclear power stations, a very wide range of purification techniques has been necessary for the treatment of effluents.

On waters working in closed circuit, decontamination has been done by means of ion-exchange agents—some of which could be regenerated while others cannot. The exchangers have been preceded and followed by special filters intended to retain all fine resin particles. This process has been used, for example, with water used for cooling reactors and for decanting ponds.

Effluents which are to be treated have been coming from laboratories, from the extraction and purification of fission materials, from the washing and decontamination plant, from the washing and regeneration fluids of the de-ionization plant and from the domestic sewer system. The design and protection of equipment has been dependent essentially upon the degree of radioactivity of the effluent.

Chemical decontamination by co-precipitation needs the use of adjuvants after flocculation by using alkaline bodies and ferrous salts. The pH could be generally adjusted in two stages. The principal radioactive elements to be eliminated have been isotopes of uranium, plutonium, strontium, caesium and ruthenium. Sludge blanket clarifiers have been specially suited to this type of treatment.

After clarification, decontamination may be done by filtration and even de-ionization. Contaminated domestic effluent has been subjected to biological treatment in addition to chemical decontamination, the usual techniques being employed. Elimination of radioactive elements has been also helped by the presence of organic sludge.

The most serious environmental problem posed by the nuclear power industry has been that of sludge disposal. This sludge, which has been often very bulky, especially in the chemical decontamination processes, must be thoroughly dried for storage in closed

shielded tanks, or encased in bitumen before burial in the ground. Expensive drying processes like freezing or evaporation are generally used. Sludge-handling installations, like the treatment plant itself, have to be extensively automated and extremely robust, for reducing human intervention to the absolute minimum.

This brief account reveals that industrial effluent problems have been generally complex and need the use of a wide range of techniques—analysis, microbiology, biochemistry, chemical engineering, civil engineering, and applied mechanics of fluids and suspensions amongst them.

Generally only preliminary trials on pilot plant or in laboratories make it possible to design the most suitable plant. The treatment of industrial effluents frequently causes large quantities of sludge ; disposing of sludge safely is just as important as treating the effluent itself. Sludge drying techniques have been able to reduce volume as far as possible, and the resulting materials are then either buried in disused dry mine shafts, or kept into special barrels for discharge at sea in deep waters.

22

Advanced Waste Treatment Methods

INTRODUCTION

A number of more advanced ("tertiary") treatment processes have been tested in recent years. The aim of these processes has been not only to improve on primary and secondary treatment or to replace biological methods by physical or chemical methods but actually sometimes to improve the waste water quality to the point at which it can be reused. The increasing costs of water supplies and the increasing emphasis on waste water quality has been leading engineers to consider more seriously the possibility of total recycling of contaminated water.

A wide variety of methods are used in advanced waste treatment and they may be introduced at any stage of the total treatment process, not necessarily only after conventional primary and secondary treatment. Their purpose may be more complete removal of pollutants largely removed by primary or secondary treatment or removal of other pollutants of importance, such as phosphates and other dissolved inorganic compounds.

1. Chemical Coagulation and Filtration

These are used together in water purification and can also be used as a waste water treatment method. There are a number of

different compounds, known as chemical coagulants, that react with suspended matter to form flocs—alum [aluminum sulfate, $Al_2(SO_4)_3 \cdot 12H_2O$], copperas (ferrous sulfate, $FeSO_4 \cdot 7H_2O$), ferric sulfate [$Fe_2(SO_4)_3$], ferric chloride ($FeCl_3$), and others. In recent years a number of synthetic, high-molecular-weight, water-soluble polymers have been developed for this purpose, one example being Calgon Corporation's polydiallyldimethyl ammonium chloride. The filtration step subsequent to coagulation can get accomplished by sand, diatomaceous earth, or any of a number of multimedia filter materials that have been developed or through the use of microscreens. Phosphates can be removed in this way using lime to precipitate them but the cost may run very high.

2. Carbon Adsorption

Adsorption of tastes and odors is an old process. "Activated carbon" is a porous and highly adsorbent form of carbon with a very large surface area. In granular or powdered form (the latter is more efficient but also harder to handle) it will adsorb many refractory organic compounds dissolved in the water. The carbon must eventually (perhaps once a year) be regenerated by heating to about 925°C in an air-steam atmosphere to burn off the adsorbed organic material ; under proper regeneration conditions the carbon losses are only a few per cent. Pilot plants using columns of granular activated carbon in place of conventional secondary treatment methods have proved successful.

3. Chemical Oxidation

Waste water treatment can also be accomplished using strong oxidants such as ozone, hydrogen peroxide (H_2O_2), or the free hydroxyl radical (OH). Chlorination with chlorine or chlorine dioxide is also possible.

Dissolved inorganic compounds are a problem because they are more common in waste water, even after secondary treatment, than they are in the water supply so that they can easily build up in a water reuse cycle. Several methods exist for demineralization :

distillation, freezing, ion exchange, electrodialysis, and reverse osmosis. Distillation and freezing have been apparently not economical but the other methods have been all useful.

4. Ion Exchange

Ion-exchange can be accomplished by the use of natural materials (such as zeolite) and synthetic materials (such as ion-exchange resins). Cation-exchange resins exchange their hydrogen ions for metallic cations in the solution passing through the ion-exchange column, while anion-exchange resins exchange their hydroxyl ions (OH^-) for chloride and other anions in the solution. The resins can be regenerated by treatment with sulphuric acid (for cationic resins) or sodium hydroxide (for anionic resins). Ion exchange is very effective and produces high quality effluents, and it is possible to mix treated water with untreated water to produce effluent of any desired quality. The cost of this treatment method has been fairly high at present. One natural zeolite, clinoptilolite, seems to adsorb both phosphate and ammonium ions and may prove to be of great value.

5. Electrodialysis

Placing an electrical potential difference across the waste water produces an electric current, making the cations to migrate toward the cathode and the anions to migrate toward the anode [see Fig. 22.1 (*a*)]. Membranes (really ion-exchange resins in sheet form) permeable to only cations or only anions are used to control the migration of the ions and permit demineralized water to be taken out of the appropriate chambers. Organic molecules are not removed and they can collect on and clog the membranes. Another disadvantage of this method has been that it still leaves concentrated waste water to be disposed of in some fashion.

6. Reverse Osmosis

Another membrane process concentrates the impurities in part of the solution and thereby purifies the other part; it is shown

schematically in Fig. 22.1 (*b*). Ordinary osmosis involves the movement of water across a semipermeable membrane (*i.e.*, one that is

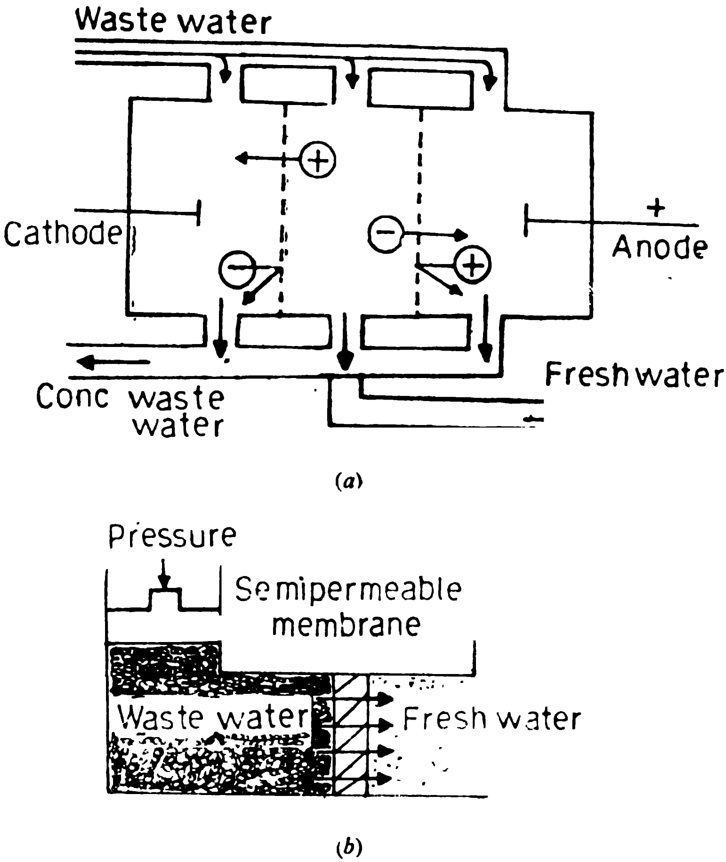

Fig. 22.1. Schematic diagrams of membrane processes for water treatment. (*a*) Electrodialysis ; C is a membrane permeable to cations only and A is a membrane permeable to anions only. (*b*) Reverse osmosis.

permeable to water but not to the dissolved material) in such a way as to tend to equalize the concentrations. Reverse osmosis is the opposite phenomenon produced by applying pressure to the more concentrated solution and thereby forcing water to the other side of the membrane. Reverse osmosis reduces both the organic and

inorganic content of the waste water but some fouling of membranes can still occur. As with electrodialysis there has been highly concentrated waste water to be disposed of. An experimental reverse osmosis plant at Pomona, Calif., led to reductions of 88% for total dissolved solids, 84% for COD, 98.2% for phosphate, 82% for ammonia, and 67% for nitrate.

7. Air Stripping

Another process can be used for removing ammonia (NH_3) from waste water. The pH of the water gets raised, usually by addition of lime, and the ammonia driven out of the solution by doing vigorous agitation with air.

8. Advanced Biological Systems

New biological methods are also being considered for waste water treatment. The use of shallow (perhaps a meter deep) oxidation ponds allows water to be purified by the action of aerobic bacteria and algae. These ponds use solar radiation for photosynthesis and the organic material is used for both bacterial and algal growth, greatly reducing BOD (and also coliform organisms, perhaps through the production of antibiotic substances by the algae). The ponds may have disagreeable odors if anaerobic conditions are permitted to exist but under proper conditions there is plenty of oxygen produced and the effluent may even be supersaturated with dissolved oxygen. The ponds eventually have to be cleaned out (perhaps every few years) and weeds must be kept under control (this is part of the reason for keeping the ponds shallow).

COSTS

The costs of advanced treatment will be some what higher than those of primary and secondary treatment but not very great considering the importance of pure water. The most advanced large-scale tertiary treatment plant is that of the South Tahoe Public Utility

District at Lake Tahoe, Calif. It handles 30,000 m^3 (about 7.5 million gal) of waste water daily and incorporates the usual primary and secondary treatment processes plus flocculation and phosphate removal with lime, ammonia removal by air stripping, multimedia filtration aided by synthetic polyelectrolytes, organic removal by adsorption on activated carbon, disinfection by chlorination, and recovery of the lime and activated carbon.

23

Advanced Techniques of Water Treatment

INTRODUCTION

A typical drinking water treatment plant is able to clarify the water and makes it hygienically safe. It may also add lime and sodium carbonate to make the water softer, and it may mix the water with activated carbon to improve the odor and the taste. The water is generally made to chlorinate at the end of treatment (sometimes at the beginning, too) with enough chlorine to kill essentially all bacteria and viruses and leave a residue of chlorine sufficient to keep the water safe until it reaches the water tap.

As water being treated for drinking purposes often is contaminated by organic substances, chlorination can produce some organic compounds of chlorine. Some that have been detected have been chloroform and carbon tetrachloride. These compounds are suspected of being carcinogens.

No alternative technology to chlorination is immediately available. Ozone is used by special permission in one very small system. Ozone has been highly toxic to bacteria, and it destroys viruses more efficiently than chlorine. It leaves no taste. The technology for the use of ozone has been somewhat more expensive

than for chlorination, and we have slight long-term experience in the use and effectiveness of ozone. Thus the government must move very carefully before requiring a switch from chlorination. Eventually that change could be made.

The methods of purifying waste domestic and industrial waters are largely traditional and have proved extremely effective in the past. However, in recent years further methods of purification have been introduced, particularly in the field of industrial water treatment.

USING OF ACTIVATED CARBON

Activated carbon has been used for sewage water treatment as a tertiary purification process following normal primary and secondary activated sludge treatment stages. The first large scale activated carbon sewage treatment plant in the world got commissioned at Lake Tahoe by the South Tahoe Public Utility District near Bijou, California, in March, 1968.

The secondary effluent from the holding pond of the activated sludge plant has been first treated with alum using two 200 litre/h metering pumps and flash mixers. The carbon beds have been 3 m in diameter and 12 m long ; each consists of a 1 m thick layer of special Micro-Floc filter medium which has been supported on 750 mml of gravel. There are two filter beds with the diameter of the particles varying continuously from 1.0 mm at the top of the first bed to 0.15 mm at the bottom of the second. The filtration rate has been 3.3 litres per second per m^2, and this rate can be maintained for 12 hours without any clog-up occurring. With conventional sand filters it only becomes possible to filter at half this rate, and even so the medium has to be changed several times per hour. Controlled dosing with a polyelectrolyte is able to reduce the amount of coagulant needed and also improves the filtration.

The carbon columns have been vertical steel tanks having a diameter of 4 m and a height of 7.5 m. Each tank is having 65 m^3 of granular activated carbon and the maximum flow rate through the beds has been about 5 litres per second per m^2. The activated carbon beds have been not stationary ; the charge gradually moves down-

wards and has been eventually withdrawn at the bottom for regeneration. In consequence the cleanest water comes into contact with freshly regenerated carbon during the downflow process, enabling even slight traces of organic impurities to be removed effectively. An impurity often present in waste waters has been the non-degradable detergent alkyl benzene sulphonate; virtually every trace of this obnoxious impurity has been efficiently removed by the activated carbon method.

Regeneration of Carbon

The activated carbon removed from the bottom of the carbon columns is first partially dried and then heated in a propane-fired regenerating furnace to 930°C in a steam atmosphere. The steam is able to vaporize the impurities which have been adsorbed on the carbon surface and drives them off. The furnace gases which carry these impurities are then allowed to pass through afterburners and a wet scrubber, before being released to the atmosphere. The carbon is quenched and a slurry is formed.

The water which emerges from the carbon columns has been allowed to pass into a chlorinator with a capacity of 900 kg per day. The tertiary plant, which is able to transform the water from the semi-treated quality, at which it usually emerges from sewage plants, to the high grade required to keep Lake Tahoe 'one of the three purest lakes in the world' cost only the dollar equivalent of £230,000 —and is having a capacity of 20,000 m^3 per day. The plant at Lake Tahoe is shown in Fig. 23.1.

Nor are the running costs of an activated carbon plant very high. The costs as experienced at Lake Tahoe are as follows, given in £ and new pence per 1000 m^3 water treated :

Loss of carbon	£ 1.47
Fuel	£ 0.22
Power	£ 0.69
Labour	£ 1.10
Maintenance	£ 0.42
Total	£ 3.90

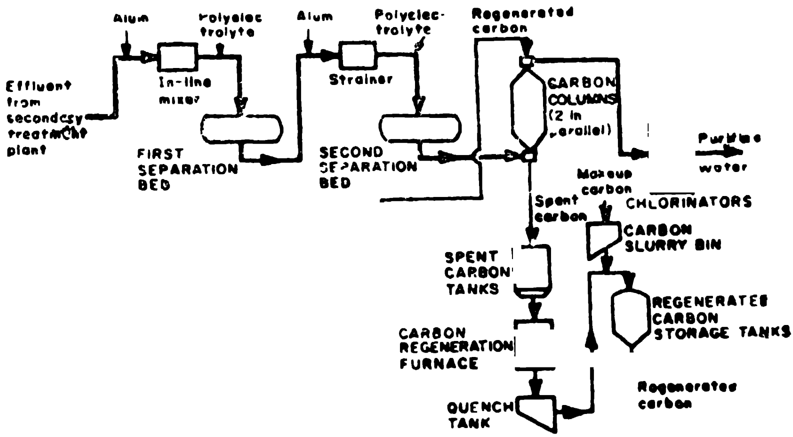

Fig. 23.1. Production of drinking water quality effluent at Lake Tahoe.

The total incremental cost of producing drinking-water quality effluent instead of the usual semi-purified effluent worked out in the Lake Tahoe project at £ 15.50 per 1000 m^3 of water treated.

Performance of the Lake Tahoe is summarised in Fig. 23.1.

A number of plants based on the highly successful Lake Tahoe plant have been constructed in other parts of the United States.

MICROSTRAINING

It is a form of simple filtration which has been using very fine fabrics of stainless steel wire drawn to diameters barely visible to the naked eye. This stainless wire has been woven on special high precision looms for producing so-called microfabrics.

Thin mats of intercepted solids could be formed on their surfaces which, together with the fabric support, are having relatively high flow ratings at low hydraulic resistance and can intercept a large proportion of solids that are *smaller* than the already minute apertures in the woven fabric. Organisms with a diameter as low as 7-12 microns could be removed satisfactorily by this method.

Table 23.1. Performance of the Lake Tahoe Activated Carbon Plant

	Incoming raw waste water	*Effluent from secondary treatment*	*Tertiary treatment*	
			Effluent from separation	*Final (chlorinated) effluent*
Chemical oxygen demand (mg/litre)	200—500	40—60	20—30	2—10
Biochemical oxygen demand (mg/litre)	180—400	15—35	52—0	2—5
Suspended solids (mg/litre)	160—350	15—20	less than 0.5	less than 0.5
Turbidity units	50—150	20—60	less than 0.5	less than 0.5
Phosphates (mg/litre)	15—35	10—30	0.4—2.0	0.2—1.0
Alkyl benzone sulphonates (mg/litre)	3—8	3—6	1—3	0.05—0.5
Coliform bacteria (probable number per 100 millilitres)	15×10^6	150,000	15	less than 2.2
Colour units	high	high	20—50	less than 0.5

Microfabrics have been unique because they combine acceptable filtration efficiencies having high porosity, high flow ratings, low filter head losses and easy removal of intercepted solids by low pressure back-washing water jets. They are also having the important characteristics of remarkable uniformity, high mechanical strength and excellent durability. Experience with early microstraining plants has postulated a possible fabric life of ten years or more.

There are three grades of microfiltration media ;

(*a*) Mark II fabric is the coarsest, and has about 10,000 apertures per cm^2. It s mainly intended for purposes where the highest filtration efficiency has been not needed. Aperture diameters have been 160 microns.

(*b*) Mark I fabric is having about 12,500 apertures per cm^2, and is used for primary filtration of impounded waters and for final filtration of effluents emerging from the sand filters of sewage purification works. The diameter of the apertures has been 90 microns.

(*c*) Mark 0, which is the finest filter of all, is having the remarkable number of 25,000 apertures per cm^2, and each opening is only 65 microns across. This grade of microstraining medium has been used for the clarification of potable water and even for filtering finished drinking water.

The weight or volume of a particle which is positively intercepted by a fabric varies having the third power of the aperture size.

Microstrainer is shown in Fig. 23.2.

Types of Materials Removed by Microstraining

Suspended particles in water may be either living organisms or inorganic in nature. Microstraining is having the function of removing both—from industrial waters or from the effluents emerging from sewage works. The main non-living particles which have been suitable for removal by microstraining have been paper fibre, humus, fly ash from power stations, metallic scale, etc. All

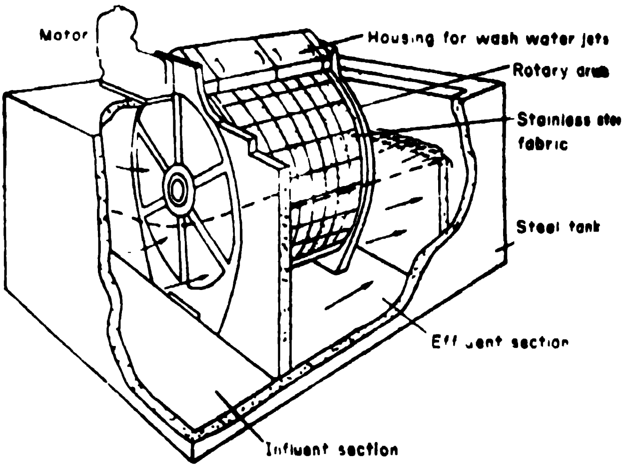

Fig. 23.2. Diagrammatic view of microstrainer.

the following living organisms could be removed by microstraining techniques :

Diatoms

Asterionella species
Navicula gracilis
Navicula rhyncocephala
Diatoma vulgare
Tabellaria flocculosa
Pleurosigma species
Cymbella species
Synedra ulna
Synedra pulchella
Fragilaria species
Nitzschia acicularis
Nitzschia sigmoidea
Meridion circulare
Melosira species
Stephanodiscus niagarae
Amphitetras antediluviana
Cyclotella species

Green Algae

Closterium species
Spirogyra species
Cosmarium species
Scenedesmus species
Ulothrix species
Pediastrum species
Arthrodesmus convergens

Other Organisms

Amoeba species
Rotifer-brachionus urceolata

Use of Microstraining Fabrics

Microstraining fabrics cannot be used in the form of fixed screens as they would become matted almost immediately. They have been best used in conjunction with self-cleaning rotary drum filters which incorporate high speed automatic washing and waste disposal.

The drum has been of bronze, which has been built up on two spoked rings, one at each end, with longitudinal junction bars connecting the rings together forming panels to which the filtering medium has been attached. Spigots on the end rings have been found to fit closely against matching spigots on heavy spoked end frames of cast iron, connected together by tie bars and supporting a central hollow axle on which the drum has been carried by two specially designed initially self-aligning bearings, fitted in the centre bosses of the spoked rings of the drum, sealed and lubricated for continuous operation. The running clearance between the drum spigots and the end frame spigots has been positively sealed by internal and external spring-loaded sealing bands. The upstream end frame is open and forms the water inlet to the machine, whilst the downstream end frame has been entirely closed. By this arrangement, hydraulic end-thrust, which can be very heavy in large units, has been diverted from the drum bearings and transferred to the static downstream end frame which is, as described, rigidly tied to the upstream end frame built into the tankwork. The hollow axle has been also carrying a waste-water hopper which discharges through the axle to a waste pipe that can be connected at whichever end of the assembly is most convenient.

The microfabric, is jointed to external machined surfaces on the drum having monel-metal cover straps, woven spun glass sealing tape, and stainless steel bolts. It is supported by coarse mesh stainless steel wire pilot cloth of suitable pitch to disallow deflection of the wash-water jets from the surface to the drum, which can take place if surface film is allowed to span the tiny apertures of the microfabric.

Cleaning arrangements is having two rows of self-clearing jet nozzles which are mounted on a header pipe fitted on top of the structure and spanning the drum width. The nozzles have been designed to provide give powerful stream lines in a thin knife-like nappe, and to have the highest washing efficiency with minimal wash-water consumption. All splashing from the jets has been confined by 'Perspex' and stainless steel splash guards which are having removable inspection panels.

Rotation of the drum has been through a bronze spur ring bolted to one end, driven by a pinion on the output shaft of an electrically-operated variable-speed hydraulic system, by which means the peripheral drum speed could be adjusted up to a maximum of 1 m/s.

A typical plant having an effective drum width of 180 cm and diameter of 2.5 m has been driven by a 1.5 kW motor, and can deal with anything between 4000 and 20,000 m^3 of water per day.

To prevent the microfabric from being clogged up by bacterial and other organic slime, the microstraining plant is often fitted with high intensity ultraviolet irradiation equipment. Operating costs are low too.

USE OF COAGULANTS

For effective removal of impurities from water it becomes essential that these have first flocculated, that is, have been in a form that could be removed readily by filtration methods. The aim has been to obtain particles in excess of 120 microns in diameter ; these tend to settle readily in typical aqueous medium. Particles between about 3 and 100 microns tend to settle too slowly for practical purposes.

Flocculation seeks to achieve agglomeration of small particles into larger units and there by speed up the settling process. The most widely used flocculating agent has been alum, a complex salt of aluminium. When this has been added to an alkaline solution a

voluminous aluminium hydroxide flocculate has been produced, which readily sinks to the bottom because it has been heavier than water. In its passage downwards it traps tiny particles suspended in the water and thus removes them.

A recent development has been the use of a number of synthetic and natural polymers. These form 'bridges' between adjacent solid particles and cause them to sediment. In many instances polymer sedimentation has been not as effective as alum, because small particles, particularly those with a diameter below 2 microns, tend to possess a (usually negative) electric charge. Alum is able to dissipate this charge through the presence of positively charged aluminium ions in solution. However, metal salts have been not without their disadvantages. They are expensive, sometimes give inadequate flocculation and may also leave a 'carry-over' of fine turbidity.

Special synthetic polymers are being manufactured which are having the properties of bridging and discharge of electrical potential. Only water-soluble monomer-polymer systems can be used for waste water clarification. The following poly-electrolytes have been used :

(*a*) *Non-ionic types.* Polyols, polyethers, polyamides, polyvinyl heterocyclics ;

(*b*) *Anionic groups.* Carboxylates, sulphonates, phosphonates ;

(*c*) *Cationic groups.* Amines, quaternary ammonium compounds, sulphonium and phosphonium compounds.

The most common of all flocculants have been the polyacrylamides which are having molecular weights in the range 4-10 million.

Use of Polymer Flocculants for Industrial Wastes

When oil has been present in the emulsified ·te in water, alum and lime have been first added to break the emulsion, followed

by the polymer. Hot mill wastes could be gravity-settled in scale pots, but the effluent from these contains particles between 2 and 70 microns in diameter. With a feed of 0.3 mg/litre of anionic polyacrylamide, the suspended solids could be reduced to about 40 mg/litre. For oil refinery waste liquors a combination of 25-100 ppm of alum followed by 1—3 ppm of polyamine has been usual. This produces a dense and large flocculate which settles well.

LIQUID/SOLID SEPARATION WITHOUT CHEMICALS

The solids in the streams coming from the main sewage treatment process have usually between 95 and 99 per cent of water. In order to enable them to be removed from the water, lime, ferric chloride or polyelectrolytes have to be added, at a cost of approximately £ 1 per 1000 m^3 treated. In the Porteous process, chemical treatment has been avoided by heating the process sludge streams to about 200°C at equilibrium pressure. The sludge has been held under these conditions for about 30 minutes, to release the water of hydration held to the solid particles. After this 'cooking' operation the solids could be separated from the liquid without trouble and can then be concentrated by conventional mechanical dewatering techniques—vacuum filters or centrifuges—to a mass having less than 50 per cent liquid.

First of all the sludge is first ground down to a particle size below 9 mm diameter. Then, it is pumped into a tank via a heat exchanger and heated to the operating temperature of 200°C by steam. This normally needs 1 kg of steam per 12 litres of material processed. The processed sludge has been discharged into thickner and finally into a pressure filtration plant.

Some 15 tonnes of solid sludge associated with 300 tonnes of water have to be removed from this.

An advantage of this method is the fact that the sludge can be landfilled without risk of spreading pathogenic organisms.

HIGH INTENSITY AERATION PROCESSES

Forced aeration of activated sludge has been a most effective method of accelerating the reaction processes because.

(*a*) It provides sufficient circulation of the sewage and activated sludge for achieving constant and intimate intermixing.

(*b*) The supply of excess oxygen is able to support the biological processes which are involved.

An example of equipment for this process is the Simples cone, which is shown in Fig. 23.3. The cone driven by a totally enclosed electric motor, rotates at between 30 and 60 revolutions per minute, is able to draw liquid through the uptake tube, and discharges it in a heavy torrent over the lip of the cone to strike the liquid in the tank with some force. This makes intense agitation of the surface and high uptake of oxygen. Thorough mixing makes the biological action to proceed rapidly and readily.

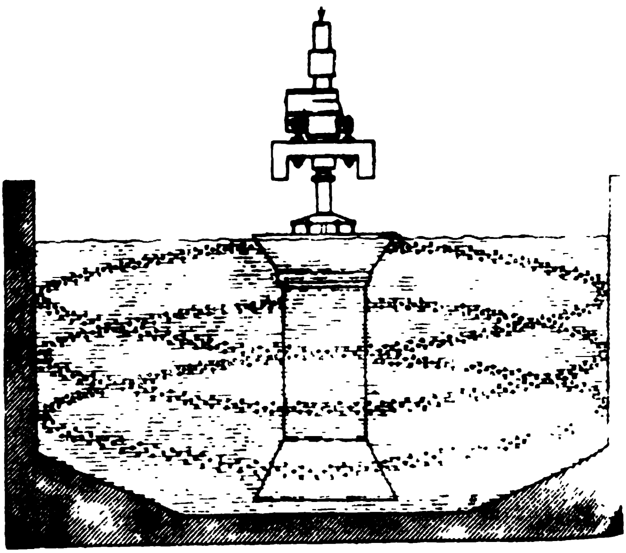

Fig. 23.3. High intensity aeration.

Another process also making use of dissolved air has been the komline-Sanderson dissolved air flotation system, which produces good solid/liquid separation and reduces light watery sludges to less than one-eighth of their former volume. Energy has been provided in the form of air bubbles, the bubbles attaching themselves to solid particles suspended in the liquid, thereby increasing their buoyancy and making them to rise to the surface. It is found easier to separate sludge from water wastes in this way than with more conventional settlement techniques, as many of the sludge particles are having densities which are close to that of water.

The most reliable means of producing the fine bubbles required for air flotation has been to dissolve air in the liquid under pressure, and afterwards reduce the pressure in the unit. Pressurization is done in part of the liquid flow which gets re-cycled from the plant. Air could be fed into this re-cycled effluent at a controlled rate and is mixed by the action of a water rejector in the retention tank. A re-aeration circuit could be included in the design to ensure a high degree of saturation. From the retention tank the re-cycle flow, controlled by a valve, passes into the mixing chamber at the unit inlet where it meets the encoming activated sludge. A sludge blanket could be formed, which has been normally between 20 cm and 60 cm thick. This rises well above the liquid level thereby enabling the float to be drained prior to being swept into an adjacent hopper by a variable-speed skimming mechanism. The clarified effluent from the rotation unit has been passing under a baffle, terminating near the floor of the tank, and a proportion is withdrawn for return to the retention tank. The remainder of the effluent could be discharged over a weir which has been adjustable for control of the liquid level in the rank.

Aeration plants can be constructed in any size. The smallest units made serve single houses, while there have been some very large installations capable of dealing with flows of around half a million cubic metres per day. The largest plant using the simplex aeration system has been the Crossness sewage treatment plant in

London, where there have been 384 high intensity cones in total tank volume of 140,000 m^3. The average biological oxygen demand which can be satisfied with a Simplex high intensity cone aeration system has been some 2.1 kg/m^3 per 24 hours.

UNDERGROUND SEWAGE WORKS IN SWEDEN

The siting of sewage works in the vicinity of large areas of population has been a frequent and difficult problem. While every-onge appreciates that sewage works have been necessary, no one likes living near them and, in consequence, land and property values close to such works could be very adversely affected.

In Sweden the practice has grown up of siting sewage work underground. The Kappala union has been comprising of 10 sub-urban communities in the Stockholm area who are collaborating in the construction of underground ducts resulting in an underground sewage works, designed to cater for the sewage flow from a total population of 540,000 people. The main sewers have been all con-structed as tunnels with very large cross-sections areas. The largest have cross-sectional area of 8 m^2, while even the minimum cross-sectional area of main ducts has been as large as 4 m^2. The total tunnel length for the area is 60 km and the maximum design flow 7.4 m^3 per second. All the tunnels could be constructed as inverted siphons and are places some 70—90 m below sea-level. The cost of the main sewer and pumping stations was very high as these large and water-tight tunnels could be laid in granite—the bedrock of the Stockholm area.

The tunnels and sewers, which got started in 1958, cost £ 6.7 million ; the necessary pumping stations cost an additional £ 1 3 million.

The purification plant was situated on the island of Lidingo, one of the largest islands of the beautiful archipelago which reaches out into the Baltic from close to the city of Stockholm. The plant has been sited underground in order to preserve the environmental amenities.

The main tunnel reaches the site of the plant 18 m below sea-level. After screening, the sewage could be lifted to the plant via a pumping station to three aerated de-gritters, and then to sin equal size tunnels, each of which contains a primary sedimentation tank, a secondary sedimentation chamber, a flocculation tank and a final sedimentation tank. Purification is done by using of activated sludge. Before final sedimentation, the sewage flows through flocculation chambers where chemicals have been added for reduction of phosphate content. The outlet consists of a tunnel equipped with a chlorine dosing system, and the purified effluent gets discharged into the sea at a depth of about 50 m. During dry weather flow the BOD reduction achieved in the plant has been about 95 per cent. The plant which has been at present able to deal with a fluid volume of 175,000 m^3 per day, retains the sewage for about 10 hours. After thickening, the sludge gets digested in anaerobic digesters and de-watered by vacuum filtration and in centrifuges. The dried sludge has been used for soil improvement, while the gas produced has been used for heating purposes.

Apart from the fact that an underground sewage plant does not interfere with the general amenities of an area, it is having other advantages The plant is not affected by the weather, and indoor working conditions are far more pleasant for the personnel operating it. Eventually, it is expected that the plant will be extended to cater for the sewage produced by about a million people.

SWEDISH MINI-SEWAGE WORKS

AB Parca, of Linkoping, have developed a simple mini-sewage works which was invented by Sigvard Nordgard. The main part of this is having a so-called biological contact rotor, which is consisting of flat spirals within a horizontal cylinder through which the effluent passes. The various micro-organisms that break down organic impurities in the sewage have been present within this unit. Features of the system have been that a special surface treatment method substantially is able to increase the effective contact area between the

micro-organisms and the effluent water, and also that the water gets forced through the rotor.

The units are available in three sizes, to tackle 3, 10 and 30 m^3 of water per 24 hours and to achieve a 90 per cent reduction in the biological oxygen demand (BOD). These small units have been built entirely in glassfibre reinforced plastics and have been suitable for such purposes as the treatment of the wastes from farms, houses which have been some distance away from towns, camping and caravan sites, and small industrial under takings.

It has been possible to increase the capacity of these mini-sewage works by keeping several of the rotors in parallel; a battery of three of the 30-m^3 units has been capable of treating the sewage from 100 private houses.

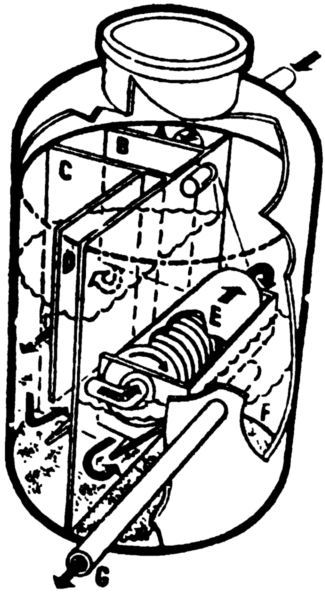

Fig. 23.4. The Parca mini-sewage plant.

REMOVING DISSOLVED SALTS FROM WATER

The various methods of sewage purification so far described have been especially designed to remove suspended matter from

water. Admittedly, some of the suspended matter has been of very small particle diameter indeed, and has been best described as micro-colloidal material, but the techniques used are basically methods of flocculation, coagulation and filtration. However, much pollution of water arises from the presence of dissolved salts, and coagulation techniques will not be able to remove these. Water having dissolved salts passes into rivers and thence flows into the sea. The salt content of seawater is having a tendency to rise because solution has been a one-way process.

Water gets evaporated from the surface of the oceans, falls down upon the earth in the form of rain, dissolves more salts and finally returns of the sea. The salinity of seawater varies from sea to sea. The average salt content of the sea has been about 3.5 per cent. There are, in fact, many large areas of brackish water (mineralized static land-water), with lower salt contents, but still too high for human consumption.

With the increasing human population and industrial consumption of water, and through the natural deterioration of many water resources due to the constant dissolution of salts in them, man will be facing the fact that he will not be able to rely completely upon natural sources for fresh water. This stage has already been reached in certain isolated parts of our globe, like Hong Kong, Kuwait and parts of Israel. Many other parts of the world have been expected to suffer from a severe water shortage in the future, and desalination processes have been certain to become 'growth industries' by the end of this century.

Fortunately a number of ways are available in which seawater and brackish water can be desalinated, but all of them have been still very much more expensive than conventional methods of obtaining fresh water. These have been consisting of collecting rainwater in reservoirs for piping to the consumer, or treating riverwater, which may be highly polluted yet contain very few dissolved salts. It has been only when these methods for obtaining fresh, clean water cannot meet demands that desalination in one form or another has been likely to be considered.

The main methods of removing the salinity in water have been as follows :

(*a*) Flash distillation ;
(*b*) Sundry other evaporation processes ;
(*c*) Solar stills ;
(*d*) Ion exchange ;
(*e*) Liquid/liquid extraction ;
(*f*) Freeze desalination ;
(*g*) Reverse osmosis ;
(*h*) Electrodialysis ;
(*i*) Hydrate processes.

Flash Distillation

Pure evaporation of seawater and other brackish water has been still the most widely used of all methods of recoverin the pure water. The heat needed to boil a kilogram (litre) of pure water at 100°C has been nearly 2.27 MJ ; but the heat needed to boil concentrated solutions of salts is greater as the presence of the salts elevates the boiling point. The main economy of the process has been dependent upon obtaining adequate heat economy.

This could be mainly achieved in two ways. First, solutions can be evaporated at lower pressures when the latent heat needed has been markedly reduced ; and second, attempts can be made to use low grade waste heat for the process, especially using waste fuels like refuse, petroleum tail gases, etc., for operating seawater distillation plants. There has been a considerable future in the operation of seawater desalination plants which use distillation on the total energy principle. The most commonly used process employing distillation as a basis has been flash distillation.

Flash distillation is involving a technique of allowing the seawater to boil successively in a large number of chambers, each of which has been maintained at a lower pressure than the one before, to match the lower temperature of the water. The method of flash distillation of seawater has been especially promising when related

to the use of waste heat produced in nuclear power stations. It has been feasible to design a nuclear power station, operating on the total energy principle, to produce 400 MW of electricity and 283,000 m^3 of freshwater per day.

Operating cycle of a flash evaporator. The flash evaporator is having twenty to fifty chambers in sequence, which are operating at successively lower pressures. When heated brine flows from one chamber to the next, some of it 'flashes' off into water vapour, which then condenses on colder condenser tubes and drops as distillate into trays to be led away into storage.

The brine, when passing from chamber to chamber, gets progressively cooler and it has been this same brine which is eventually pumped back through the condenser tubes to act as the coolant in the condenser section of each chamber. It becomes progressively hotter as it does this ; consequently, when it reaches the heat input section before re-entering the first flash chamber, its temperature need only be raised a few degrees. The heat would be normally supplied by low-pressure steam which, in its turn, has been readily obtained by utilization of waste heat from primary power generating sources.

As can be seen from Fig. 23.5, the heated brine has been passing from the heat input section to the first flash chamber (1) and from there successively through all the chambers down to the coolest one (6), flashing off a certain amount of water vapour at each stage. It could be then extracted by the brine circulator pump and returned to the tubes of the heat recovery section at (4). In the last few stages—the heat rejection section (5 and 6)—cold crude seawater has been pumped through the tubes.

This allows condensation to occur in these stages and also extracts an amount of heat equal to that put into the evaporator at the heat input section, thereby allowing permitting a continuous cycle of operation. Some of the seawater, after chemical treatment to disallow scale formation, is added to the circulating brine to make up for the distillate extracted and for brine which must be discarded

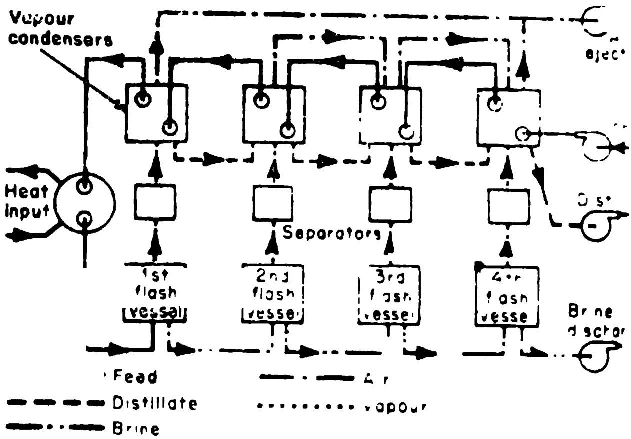

Fig. 23.5. Layout of a multi-effect flash installation using waste heat from diesel engines

in order to keep the solute concentration in the evaporator within specific limits.

When seawater has been heated, gases such as oxygen and carbon dioxide are given off. These could be extracted by a vacuum pump or ejector system.

The heat needed in a flash evaporator to produce unit weight of distillate has been given by the following equation :

$$(t_e - t_1)/(t_e - t_f) = L$$

where t_e represents the temperature of the water entering the flash stage in °C ;

t_1 represents the temperature of the water leaving the tube system in °C ;

t_f represents the temperature of the water leaving the first flash stage in °C ;

L represents the latent heat of flashed vapour in kJ/kg.

Capital costs for typical evaporator plants have been found to depend upon the operating efficiency. Low-efficiency plants are having a $(t_e - t_1)/(t_e - t_f)$ ratio of 0.25, while the ratio for high-

efficiency plants has been of the order of 0.1 or less. Thus low-efficiency plants are having a fuel consumption which has been $2\frac{1}{2}$ times as high as that of high-efficiency plants.

Sundry other Evaporation Processes

Apart from flash distillation, many other processes have been employed with some success.

(*a*) *Thin film evaporation technique.* This employs double fluted tubes to improve the heat transfer coefficient between the heating medium and the saltwater to be heated. An experimental plant was built at the University of Toronto ; heat transfer coefficients of the order of 100 kW/m^2 per °C got achieved. In 1962 a twin-effect thin film distiller for marine service was installed on the S.S. *Tullahoma* having a capacity of 30 m^3 per day. Scale control was achieved by adding phosphates to the feed water. A thin film evaporator having a capacity of 150 m^3 per day was built at Wrightsville Beach, North Carolina ; this is also a twin effect plant and operates at 135°C.

(*b*) *The multiple effect rotating evaporator.* It is having a steel drum which is able to rotate about a vertical shaft and contains a stack of concentric circular copper plates 1200 mm in diameter and 12 mm apart. Seawater is allowed to enter at the centre of the top plate and is thrown towards the periphery by centrifugal action. All this produces a very thin film of water which has been constantly moving outwards. A plant with a capacity of 35 m^3 per day is having an output of 16.5 kg of product for each kg of steam used. Assuming mass production of the units, the cost works out at about 7p per m^3 of freshwater produced.

(*c*) *Nuclear desalination plants* The use of nuclear energy has been most attractive from the point of view of operating desalination plants. Countries which are shortage of water are often also deficient in natural fuels. At any rate, as far as the future is concerned we must start thinking of preserving precious hydrocarbon stores.

In the Soviet Union there are some nuclear desalination plants which have been built using organic liquid cooled reactors having capacities of 30 and 70 MW. The heat is given off to a hydro-terphenyl coolant, which can be heated up to 350°C without appreciable rise in vapour pressure. The plants so far built in Russia are having capacities of 150 and 500 m^3 per hour and promise to assume greater importance in future for the supply of water to communities far away from natural sources of potable water.

(*d*) *Vapour compression distillation.* A typical plant of this type has been situated at Roswell, New Mexico. Brackish water feed has been first 'softened'—the calcium ions could be replaced by sodium ions—to avoid scaling on the heat exchanger surfaces. It has been then acidified to a pH of 4 with sulphuric acid and enters a vacuum degasifier where CO_2 is removed. Next it has been neutralized by adding sodium hydroxide, heated by passing through a series of heat exchangers and mixed with recirculating brine solution in the first effect of a multi-effect evaporator.

The brine in the first effect has been concentrated by 1.6 to 1 and in the second effect by 4 to 1. The steam derived from the second effect evaporated gets compressed and superheated, then passed to the heating chest of the first effect. The plant is having a capacity of about 4000 m^3 per day of freshwater and the cost works out at between 4.3 and 6.8p per m^3 of water output.

Now most of the largest desalination plants, and also the cheapest to operate, are run according to one of other of the direct distillation principles. With the inevitable increase in primary fuel prices this may not always be the case.

Solar Stills

These methods have been likely to gain importance in areas of the world where fuel is scarce but there is adequate heat from the sun. Solar radiation energy available in many parts of India and Pakistan has been of the order of 20 MJ per m^2 land surface area

per day for some five months in the year, and even in mid-winter the solar heat has been still more than 10 MJ/m per day.

A system developed in India uses a large area of glass positioned between 30 and 60 cm above a surface painted black, along which seawater is allowed to flow. Solar heat makes water to evaporate, leaving the salt behind, and condensation takes place on the glass cover. The water drips off to an aluminium channel and runs to a storage vessel. The unit has been also equipped to collect rainwater. The cost of getting water from the experimental 2 m^3 per day stills, which have been able to extract around 3-4 litres of distilled water from each m^2 of still surface erected, is about 18p per m^3. It is now thought that with larger installations it becomes possible to use this system anywhere where the present cost of water exceeds 70p per 1000 U.S. gallons or 18.5p per m^3. Such conditions

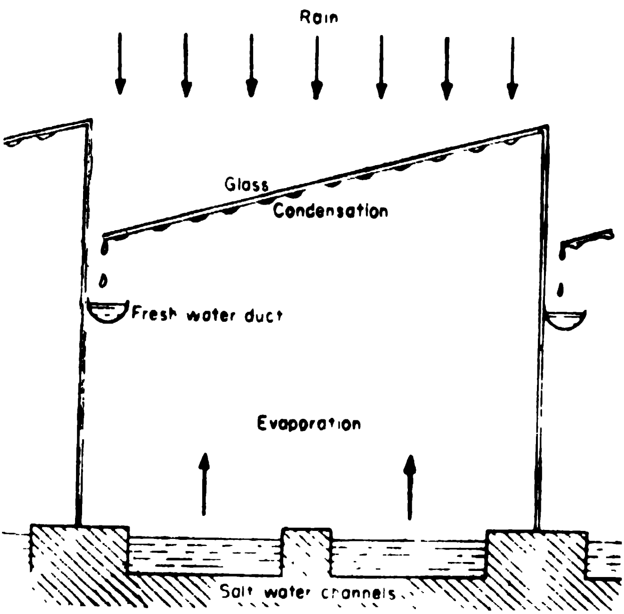

Fig. 23.6. Use of solar energy for desalination of salt water. The large 'greenhouses' are also used for the collection of rain water.

have been found in many parts of India and other arid regions of the earth.

A large solar distillation plant was built near Daytona Beach, Florida. The feed water is having 3.2 per cent dissolved salts and the area of land covered is 220 m^2. Each unit is consisting of grooved concrete curbs laid 1 m apart to form a bay 20 m in length.

There have been plastic basin liners and clear plastic cover domes. Underneath the brine has been a thick layer of insulation, so that the heat generated inside the still has been not conducted away to the soil. Water evaporates from the feed water and condenses against the plastic dome cover, running down towards galvanized steel distillate troughs at the sides of the stills. Solar stills, based on similar designs to the above, are also erected in Greece and Spain.

For a basin type solar distillation plant, with a capacity of 180 m^3 of water per day, covering a ground area of 50,000 m^2 plant investment cost has been about £ 2,00,000 ; as far as running costs are concerned, amortization accounts for 70 per cent of the daily costs.

The next major items of expenditure have been taxes, insurance and interest on working capital, which add a further 18 per cent. The final cost of water supplied works out at 35p per m^3—very much higher than with distillation systems which use purchased fuels.

However anomalous it may be that where the fuel has been free the costs has been higher, it has been certain that solar stills will not be economic in comparison with other methods of water desalination for many years to come.

Ion exchange

The cations commonly present in natural waters including seawater, have been calcium, sodium, potassium, magnesium, iron, and traces of other metals like manganese, aluminium, copper and zinc. The usual anions have been bicarbonate, chloride, sulphate and traces of nitrate and fluoride.

Ion exchange purification takes place by passing water first through an exchanger where cations get exchanged for hydrogen ions, followed by passage through an anion exchanger bed where acid radicles have been replaced by hydroxyl ions so that :

$$H^+ \text{ (hydrogen ions)} + OH^- \text{ (hydroxyl ions)} \rightarrow H_2O \text{ (water)}.$$

Naturally, it becomes necessary to reclaim both the cation and the anion exchange resins as they become spent. This is normally carried out by reacting the former with strong acid and the latter with custic soda. There have been a number of more sophisticated plants including so-called 'mixed bed' de-ionizers where special methods of fluidization are able to separate the different ion exchange resins to enable them to be reclaimed separately. In the past it was regarded uneconomic to use ion-exchange plants for the desalination of water with a solids content in excess of 1.5 g per litre.

By employing a cascade system of desalination it now becomes possible to treat water with a salt content well in excess of 10 g per litre. Some Russian plants have been using ion-exchange membranes for the desalination of waters having up to 15 g of salt per litre. The technique used has been a combination of electrodialysis and ion exchange using membranes which are referred to simply as MK—40 and MA—40. These are having as surface electrical resistance of about 12 ohm/cm^2, measure 150 cm $\times$ 50 cm have been able to exchange between 2.3 and 4.4 mg equivalents of ions per hour. The total electric power consumption needed has been 9 kWh per m^3 of drinking water produced.

A new American technique employs weak electrolyte ion exchangers to change sodium chloride into sodium bicarbonate first, followed by removal of the cation (sodium) and then recovery of the carbon dioxide which is still present in solution. It has been reported that with this technique really concentrated solutions of salt could be treated efficiently and economically. The 'Sirotherm' process has been an ion-exchange process in which regeneration of

the resin has been by heat and not chemicals. At present this this process has been still at the laboratory stage, but there have been indications that it has been technically, feasible to treat water with a salinity of up to 3 g per litre. It is thought that some other process may be required to reduce the salt content of seawater from its usual 35 g per litre to that at which an ion-exchange process is feasible. This implies a combination of electrodialysis or reverse osmosis with an inexpensive ion-exchange technique like 'Sirotherm'.

Liquid/liquid Extraction

In this process organic solvents have been used which will be able to dissolve water, but will not dissolve salts. So far the best solvent found for this purpose has been a mixture of triethylamine and diethyl methylamine. A pilot plant was built by the Brown and Root Corporation in Texas for investigating the possibilities of the method.

The feedwater has been brackish water having 5 g/litre of dissolved salts. The plant has been designed to deliver about 8 m^3 drinking water per day. The extraction temperature is between 18°C and 50°C, and the solvent can be driven off from the water by heating it about 20°C above its extraction temperature, for which low grade heat only is required. The solvent has been then reclaimed and returned to the extraction plant.

The Carr—Callery desalination process has been used for the desalination of seawater and use either a di-isopropyl amine propane system or a *n*-butanol-butane system. Seawater having a solids content of 35 g/litre gets separated into a brine fraction containing 120 g/litre and a water fraction with only 0.5 g/litre. Water and solvent could be then separated from each other by heating. The amount of solvent which gets retained in either the final water or the brine is as low as 5 ppm.

Freeze Desalination

The latent heat of converting water into ice has been only some 330 kJ/kg which has been far lower than the value of over 2000 kJ/

kg to convert water into steam. Ice has been able to hold almost no dissolved salt ; for this reason it would appear that freeze desalination must be cheaper than desalination by distillation. Unfortunately, although the power requirements of freeze desalination processes have been low, the capital cost has been extremely high.

A technique given by the U.S. Carrier Corporation is known as the 'direct freezing' method, in which refrigerants have been mixed with the salt solution, and the mix cooled so that ice crystals could be produced inside it. A 60 m^3 per day pilot plant was built in North Carolina and has been used for seawater desalination.

The refrigerant employed has been octofluorocyclobutane, which has been completely non-toxic and resists hydrolysis. The seawater has been first de-aerated and then pre-cooled in a conventional vapour compression refrigeration plant. The refrigerant has been added and the mix put under vacuum, which allows partial evaporation of the refrigerant and some water vapour.

This cools the seawater so that ice could be formed, which has been filtered off, washed and melted to give the product. The residual brine is heated to drive off the remaining refrigerant and is utilized as a valuable by-product.

At Eilat in Israel a vacuum freezing vapour compression plant has been in use. Pure ice crystals could be produced in brine simultaneously with flash evaporation of part of it. These ice crystals have been then separated from the carrier brine, washed, and the washed crystals have been brought into contact with compressed vapour, when the vapour condenses, the ice melts. One of the advantages of the system has been the fact that power consumption has been very low—at the present time about 11—14 kWh per m^3 of water produced, but with improvements in design this figure may well be lowered to 7-9 kWh per m^3. The Eilat plant has been consisting of four modules, each with a capacity of 10 m^3 per hour. It treats water drawn from the Red Sea, which has a salinity of 4.2 per cent.

Each module has been consisting of two adjacent cylindrical vessels, each with a diameter of 4.00 m. One is acting as the washer and the other as the freezer and melter. There has been a vapour compressor underneath the dome. This sucks out water vapour from the freezer and compresses it to pass into the melter while the ice has been taken off from the washer and passes down a chute.

It is thought that modules having a capacity of 500 m^3 per day could be built, so that an 8-module plant having a capacity of 4000 m^3 of freshwater per day has been a practical possibility at a cost of about £ 550,000. Operating labour costs have been very low and there are virtually no scale and corrosion problems, so that the final product cost could be as little as 13p per m^3.

In general, freezing desalination processes are having the following properties :

(*a*) They have been operating at low temperatures—thus minimizing scale and corrosion problems ;

(*b*) In the freezing and melting stages, heat transfer takes place in the absence of a heat transfer metal surface—again helping the avoidance of scaling ;

(*c*) Freezing has been especially suitable for treating economically water with a very high salt content—nearly all other techniques have been less effective at high solid concentrations ;

(*d*) With freeze desalination direct electric power could be used without the need to generate steam—likely to be of particular advantage for utilizing cheap electricity generated, for example, by nuclear reactors during off-peak periods ;

(*e*) Freezing processes can use a much higher proportion of brackish or seawater than other processes—but have been unlikely to be able to compete with distillation processes when very large quantities of water are to be treated (over about 400 m^3 per day).

Reverse Osmosis

When we keep a solution on one side of a semi-permeable membrane and pure solvent on the other, the solvent will pass through this membrane to dilute the solution. The pressure which gets exerted by the solvent as it passes through is called the osmotic pressure.

Indeed, it is to be argued that in solution a dissolved salt behaves like a gas and obeys the gas laws. This implies that one gramme mole of cation or anion dissolved in 22.414 litres of water gives an osmotic pressure of exactly 1.013 bars (1 atmosphere) at a temperature of 0°C. Reverse osmosis has been found to depend upon the use of a semi-permeable membrane, which is capable of being traversed only by water and not by salt, combined with pressurizing of the solution so that water passes through the membrane, but the salt stays behind.

Due to the high pressures involved, the main difficulty has been in the making of a semi-permeable membrane of adequate strength. In general, membranes could be supported by a special carrier. The following semi-permeable membrane materials are tried, with favourable results :

(*a*) Cellulose acetate dissolved in glacial acetic acid together having small quantities of additives like magnesium per-chlorate before being allowed to solidify on the carrier ;

(*b*) A cellulose acetate/formamide solution in acetone ;

(*c*) Ethyl cellulose mixes.

The working pressure on one side of the reverse osmosis cell has been normally of the order of 100 bars, while the other has been at atmospheric pressure. Supporting the semi-permeable membrane to avoid breakdown has been therefore a problem of considerable magnitude.

The first reverse osmosis plants was using perforated stainless steel plates and tubes as supports, but these have been reported to be

too expensive for commercial plants. The best material found which was having the requisite strength and at the same time was not too expensive was fibreglass cloth laminate about 3 mm thick ; this is having a compressive strength of 15 MN per m^2 and a tensile strength in excess of 150 MN/m^2. As far as tubular support materials are concerned, phenolic resins having a wall thickness of 2.5 mm seemed to provide some of the best results at the lowest cost.

Thc desalination cell has been so designed as to bring the saline solution at high pressure in contact with the semi-permeable membrane, with either plates or tubes to support the membrane itself. As osmotic pressure tends to increase with increasing salinity, the throughput rate for a given membrane is less with seawater (3.5 per cent dissolved solids) than typical brackish water (less than 0.5 per cent dissolved solids). The final product usually is having about 2000 ppm of dissolved solids, and may have to be purified further by other means.

Reverse osmosis has beed found to be more economical for low salt content water than for seawater. As the osmotic pressure of seawater has been approximately 25 bars, it has been obviously necessary to overcome this pressure before reverse osmosis can begin. Osmotic pressure builds up as the feed stream is concentrated, and this very much is able to limit the percentage of water in the feed which can be usefully recovered as freshwater ; only about a third of the water can, in fact, be recovered. Recovery of some of the power from the flow of the waste stream of concentrate seawater has been usually attempted.

It is found that a reverse osmosis plant producing 40 m^3 of water from seawater would cost about £ 3.5 million, and its operating cost would be 4.5 p per m^3 of water obtained. A plant to recover pure water from brackish sources would be costing about £ 1.1 million with an operating cost of only 2.3 p per m^3.

In spite of the disadvantages of reverse osmosis, this system has becn likely to become one of the most important in the field of water desalination.

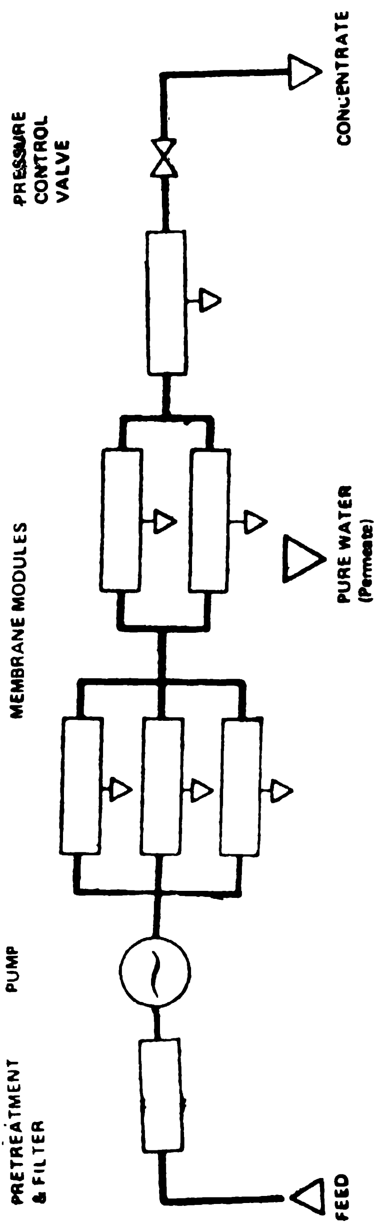

Fig. 23.7. Reverse osmosis flow sheet.

Practical reverse osmosis plants. Unlike many of the other desalination processes, reverse osmosis has emerged from the pilot plant stage and has been now used industrially. Paterson Candy International make reverse osmosis plants able to supply drinking water from brackish sources to private houses, hotels, farms, small industrial undertakings, etc.

The units are using a feed of brackish water with a maximum dissolved solids content of about 1 per cent and pH between 3 and 7.5. The salt reduction achieved has been between 85 and 95 per cent, depending upon the nature of the ions. The semi-permeable membrane in Paterson Candy units has been modified cellulose acetate cast on the inside of disposable paper/polyester tubes.

Normally membranes can find use continuously for between 12 and 24 months before replacement becomes necessary. An electric motor has been used to produce a pressure of 40—80 bars, depending upon the nature of the feed. Power consumed is, on average, about 2.5 kWh/m^3 of desalinated water—which compares favourably with 12 kWh/m^3 for distillation and 7 kWh/m^3 for freezing processes.

A plant measuring $2.6 + 1.5 \times 1.3$ m and weighing under 2 tonnes has been able to produce 45 m^3 of desalinated water per day. This has been incidentally, the largest plant currently made by this firm, which produces equipment having capacities from 2.3 to 45 m^3/day.

Electrodialysis

In electrodialysis, as in reverse osmosis, a semi-permeable membrane permits pure water to pass, but stops salts. Whereas in reverse osmosis the passage of water through the membrane has been induced by physical pressure acting on the saline solution, in electrodialysis this work has been carried out by an electric current.

The basic idea has been that the saline solution has been enclosed by membranes and an electric current induces cations

(metals) to migrate outward towards a cathode, and anions (the non-metallic ions) to migrate towards an anode, thereby progressively desalinating the solution.

Unfortunately, the procedure in practice has been not quite as simple as this. For progressive desalination to continue, the energy exerted during the electrodialytic process must also overcome osmotic pressure which is able to force clean water back into the solution.

As in reverse osmosis, membranes have to be very tough indeed for withstanding the high pressures applied. At the present time electrodialysis has been most widely used in the Soviet Union, and the most common membrane has been polyethylene backed by nylon fibre.

In general, the greater the current density used in any given dialysis cell, the smaller the area of membrane required. But increased current density also necessitates increased flow rate to prevent the membrane from being polarized. Optimum current density has been found to vary with the concentration of salts in water to be treated, the cost of the membrane and the cost of the power expended.

For seawater having a salt content of 3.5 per cent and a power cost per kWh amounting to 0.14 per cent of the cost of membrane per m^2, the optimum current density has been 1.06 A/dm^2. For other conditions, the optimum current density may decrease between 0.7 and 3 A/dm^2.

Electrodialysis desalination finds use in the U.S.S.R. mainly for water supply in sparsely populated areas, farms and watering places at distant pastures—as well as for expeditions venturing to areas where there has been no fresh water but there has been access to underground or surface salt water. Although the process has been basically an expensive one—both from the point of view of initial cost and of power needed—it is having the considerable advantage that it can be completely automated, needing no resident labour.

In Western countries electrodialysis for seawater desalination has been not generally regarded economically viable compared with other methods, mainly due to the large quantities of power needed. However, if at some future date the cost of electric power must fall appreciably, electrodialysis may become competitive.

Separators of expanded rigid PVC have to be used to support the membranes and to create turbulence in the stream. Two plants have been built, one with a daily output of 77 m^3 and the other with a daily output of 151 m^3, using membrane areas of 12 and 40 m^2 respectively.

The biggest American electrodialysis plant is the 2460 m^3 per day plant at Buckeye, Arizona. This brings down the salinity of the water from approximately 2.1 per cent to 0.5 per cent at a cost of about 5p per m^3 of water treated. Electrodialysis provides the most economic results when the installed plant capacity is large and when the feedwater salinity is comparatively low.

The Hydrate Process

The most unusual process, which has been developed by the Office of Saline Water, United States Department of the Interior, has been based on the use of various organic and inorganic gases which form solid crystalline hydrates when dissolved in saline waters under appropriate conditions of temperature and pressure.

These crystals could then be washed and melted to release the water and for recovery of the gaseous agent. One of the most suitable gases has been propane, which forms a hydrate that freezes with water over a temperature range of 0°C to 7°C comprising 17 molecules of water of crystallization combined with 1 molecule of propane. A 70 m^3 per day pilot plant was built at Wrightsville Beach, North Carolina. The seawater has been first fed into two heat exchangers and cooled. It has been then used to wash the concentrated brine from the propane hydrate crystals.

Liquid propane has been fed into the crystallizer where it serves a dual function—to cool the brine and to form the propane

hydrate crystals. The slurry has been then pumped to the washing system where it has been first washed by seawater and then by fresh water on a counter-current system. It then passes into the melter where pure water gets separated from the propane. No cost figures have been yet available for this system.

METALS AND METALLIC IONS

The release of metals into the environment has been undesirable due to two important reasons :

(*a*) The exhaustion of easily accessible reserves of the metals concerned ;

(*b*) The toxic nature of many of the metal ions.

In the world metal reserves at an alarming rate today, particularly through the activities of the motor, electronic and refrigeration industries. The manufacture of their products needs large quantities of many metals, and a high manufacturing and usage rate could be also maintained artificially by way of 'planned obsolescence'.

Few of the metals used have been at present adequately reclaimed. Lead finds wide use as a petrol additive, and gets lost to the atmosphere during combustion. Silver finds use in the photographic industry, but reclamation is negligible.

The metals presently at particular risk of exhaustion have been lead, tin, mercury, silver, tungsten and platinum. Several authorities are able to forecast that these metals will become very rare indeed before the turn of the century. Many others—nickel, chromium, uranium, vanadium, copper and several less well-known metals—have been also at risk.

Appreciable supplies are available of aluminium, titanium, magnesium, iron, sodium, beryllium, arsenic, calcium and potassium. It has been possible in many situations to substitute plentiful materials for metals that have become rare ; for example, the building industry now employs plastic components in positions where a few decades ago lead would have been used, and sheet aluminium

roofs have been replacing copper roofs. But there has been no excuse today for uncontrolled dissipation of valuable raw materials known to be approaching the point of exhaustion—even if this implies that the doctrine of 'planned obsolescence' must now itself be declared obsolete.

TOXICITY OF METAL IONS

It is possible to classify the toxicity of metal ions in drinking water or food as follows :

Highly toxic ions, which can bring about death or severe irreversible injury after short periods of exposure, include those of antimony, arsenic, beryllium, cadmium, chromium, indium, lead, mercury, thallium and uranium.

Of these, lead, mercury, cadmium and beryllium have been especially harmful, and severe cases of poisoning have taken place throughout the world. Lead—even when ingested in small quantities —causes brain damage in children, and cadmium causes severe bone damage. The dangers of mercury and beryllium poisoning have been accentuated by the fact that certain organisms tend to concentrate these ions. In addition, most of these metals have been 'cumulative' poisons ; the human body is having no means for excreting them.

Moderately toxic ions have been those which can bring about reversible and irreversible health changes after relatively prolonged periods of exposure but do not, in general, cause death. Metals in this category have been including barium, boron, copper, germanium gold, lithium, manganese, rubidium, selenium, tellurium and vanadium.

Slightly toxic ions have been those which, when ingested in larger quantities, can bring about temporary illness, but which are not having permanently adverse effect on health. Metals in this category have been bismuth, cerium, cobalt, iron, gallium, magnesium, molybdenum, nickel, potassium, silver, titanium and zinc.

Non-toxic ions, even in appreciable quantities, include aluminium, calcium, sodium, strontium and tin.

Metals such as nickel and zinc, which have been only slightly toxic to man, can be highly toxic to some plants and animals, and may therefore bring about damage to agriculture and fishing.

Stopping the Spread of Toxic Metals

Metals get released to the environment in three ways :

(*a*) In the form of fumes, vapours and other air-borne effluents ;

(*b*) In the form of solid wastes and sludges ;

(*c*) In the form of solutions as metallic ions.

In order to remove air-borne metallic pollutants from industrial processes there are standard types of equipment—cyclones and electrostatic precipitators. At the present moment there has been a high rate of release of lead, beryllium and other metals from motor fuel, to which these metals have been added as 'anti-knock' agents and to increase the octane number. There have been moves afoot to limit this in the future, and research has been in progress to develop an economic high-octane motor fuel which does not require the addition of toxic metal salts.

Toxic metals from solid waste products only would become dangerous when leached out by water and allowed to pass into drinking water or into growing plants likely to become food. Neither the burial of untreated sewage sludges nor its direct use as fertilizer must get encouraged ; these practices are reported to be responsible in the past for heavy pollution of agricultural land and water sources with metals like lead, cadmium and beryllium—all highly toxic and hazardous to public health. It has been far better to burn sewage sludge and to treat the resultant ash in other ways.

If metals have been valuable, it becomes often worthwhile to reclaim them by appropriate chemical processes. If they have been not, they must be buried in leak-proof underground caverns ; old

mine shafts can be water-proofed with concrete linings and have been then available as 'mortuary chambers' for a variety of toxic wastes, like oxides of arsenic, beryllium compounds and even certain radioactive waste materials.

Removal of Metal Ions from Aqueous Solution

Metallic ions have been present in aqueous liquids either as suspensions or in true solution. If the metals get suspended, it has been necessary to find a coagulating agent which alters the size of the suspended sol particle into one large enough to get removed by standard filtration techniques. Polyvalent salts like alums have been particularly effective for this.

If metal ions are present in solution, they could be removed by three basic methods, alone or in combination :

(*a*) A insoluble salt may get formed which can then be filtered off.

(*b*) Ion exchange methods are used.

(*c*) Solvent extraction techniques are employed.

Removal as Insoluble Salts

The first stage has been the filtration of the effluent, if necessary employing preliminary coagulation for removing colloidal materials. Next the effluent could be concentrated in an evaporator circuit.

Generally all metals form some insoluble compounds, and the choice of that compound most suitable for precipitation of a given metal could be governed both by the solubility product of the compound and by economics. The solubility products of the insoluble silver halides have been as follows :

$AgCl$	5.9×10^{-10} (g-ions/litre)^2
$AgBr$	7.4×10^{-13} (g-ions/litre)^2
AgI	6.6×10^{-14} (g-ions/litre)^2

This means in practice that if the pure salts have been in contact with water, 1.5 ppm of AgCl, 0.08 ppm of AgBr and 0.03 ppm of AgI will get lost as dissolved silver salts in the wash water.

But the term 'solubility product' has been given to the product of solubility of the anion and the cation of a salt, each expressed in gram-ions per litre. By keeping the solubility of one ion of a salt high, the solubility of the other could be automatically depressed, thus when silver chloride has been in contact with a normal solution of hydrochloric acid, the concentration of the chloride ion has been one gram-ion per litre, and the solubility of the silver ion would be :

$$5.9 \times 10^{-10} \text{ (solubility product of AgCl)} = 1 \times \text{solubility of } Ag^{+}$$

The solubility of Ag^{+} is equal to 5.9×10^{-10} gram-ions per litre or, expressed as a weight, about 6.4×10^{-5} parts per million—a truly negligible quantity.

The general rule has been therefore to reduce the solubility of the metal ion to be removed by increasing the amount of the other ion present. Lead could be best removed from solution by precipitation as the phosphate or the carbonate, both of which are having extremely low solubility products. In the presence of free phosphoric acid, for example, the lead remaining in solution has been virtually nil, as the solubility product of lead phosphate is of the order of 5×10^{-12} (g-ion/litre)^2. In a normal solution of phosphoric acid the amount of lead in solution would be only about $5 + 10^{-7}$ parts per million, or about half a milligram of lead in a thousand cubic metres of effluent.

It could be seen that provided a metallic ion has been forming an insoluble compound—and most metallic ions do—it could be removed from solution by precipitation followed by efficient microfiltration.

Problems could arise with precipitation methods when the metal has been not in the form of a simple ion, but in that of a complex with organic or inorganic chemical groups. We know that

silver chloride is an extremely insoluble compound. Therefore, silver chloride diamine, $Ag(NH_3)_2Cl$, is very readily soluble in water. Where these complexes have been present, appropriate chemical treatment must be done to break them down prior to precipitation or ion exchange processing described below.

Ion Exchange Techniques

There are four basic ion exchange resins which have been able to absorb even small quantities of dissolved cations from solutions. These have been sulphonic-phenolic resins, sulphonated coal, carboxylic resins and sulphonated polystyrene. For all of them the reaction which occurs can be expressed as :

$$H\overline{R}+M^+\rightarrow M\overline{R}+H^+$$

where M^+ represents the metallic ion (its valency does not have to be one) and $\overline{R}$ is the net-like resin structure. Once the ion exchange resin gets absorbed its capacity of metallic ions, it could be reclaimed by means of a strong acid :

$$MR^-+HCl\rightarrow H\overline{R}+MCl$$

The metal can then be able to recover from the concentrated chloride or other salt. Ion exchange of this type has been found to be very effective for many metals especially, lead, copper, zinc, mercury, chromium and nickel. For arsenic an anion exchange resin is able to remove the metal in the form of arsenates and arsenites ; reduction of arsenic contents of waste liquors to below 5 ppm can be attained without difficulty.

Copper and zinc can be removed from waste liquors so effectively that a final effluent is having less than 0.001 ppm of either metal. It has been vitally necessary, as it has been shown that even concentrations of 0.02 ppm of these metals are having very harmful effects on fish.

Ion exchange techniques must be used, where possible, in conjunction with precipitation methods, because they have been most successful when the initial concentration of dissolved metal ions has been already fairly low.

Solvent Extraction

Many solvent extraction techniques have been developed recently for removing dissolved metal ions from effluent liquors. Nickel and zinc, for example, could be removed by di-nonyl naphthalene sulphonic acid (DNSA) and di-2-ethyl hexyl phosphoric acid (EHPA) respectively Extraction efficiencies of over 99 per cent can be attained by both methods. Quaternary amines could be extracted up to 99.9 per cent of copper from dilute solutions and a number of other similar extraction techniques have been developed to deal with metallic ions which have been difficult to remove by other methods.

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Methods Used for Overcoming Shipping Pollution

INTRODUCTION

The major water pollution problems of watercraft have been sewage and oil pollution.

Vessel Sewage

The 10 million watercraft of all types (most of them recreational) have been estimated to contribute sewage and other oxygen-demanding sewage equal to the domestic sewage of 500,000 persons, most of the wastes being dumped raw into the water. There are even floating industries contributing organic wastes. Although vessel sewage is only a small part of the overall water pollution problem, there are places in which it is regarded as the major problem.

The economics of large-scale municipal waste water treatment plants are impossible to attain on even large vessels. Current sewage disposal systems for vessels include the following :

1. Holding tanks for receiving and storing sewage until they can be unloaded on the shore. Despite their simplicity they are relatively large and heavy and may require the

use of odor control chemicals, and shore facilities for unloading are generally inadequate.

2. Incinerators for incineration of human wastes.
3. Biological treatment systems which are similar to municipal secondary treatment systems. These are large and heavy and applicable only to large vessels.
4. Maceration-disinfection units that simply macerate and disinfect the wastes, without actually reducing the BOD load.
5. Chemical recirculating flush toilets such as those manufactured by Monogram Industries for use on Jet aircraft. Small units are available that can be used 160 times with only 15 litres (4 gal) of water and a single charge of chemicals.

Oil Pollution

Oil pollution from accidents involving large tankers and offshore drilling rigs has periodically attracted national and international attention in the past few years. In the best-known recent accident, the *Torrey Canyon*, carrying over 100,000 metric tons of Kuwaiti oil for the Union Oil Company, ran aground off Cornwall, England on March 18, 1967, eventually releasing most of its cargo into the water as the ship broke into two and later three parts.

Since the *Torrey Canyon* incident, several dozen large tanker accidents have been reported each year, and a great deal of effort has gone into trying to contain the oil spills that result or prevent some of their harmful effects. Three methods have been tried without much success : (1) surrounding the oil slick with some sort of mechanical barrier until it can be removed ; (2) collecting the oil by mechanical means such as suction pumping or absorption by straw ; (3) dispersing the slick with chemicals. All these methods are slow and expensive.

A more continual problem with oil tankers is that part of each cargo is generally discharged into the ocean. A tanker will carry a cargo of crude oil from the source of the oil to some port, discharge it, and fill the tanks up with seawater to act as ballast on the return trip. Before the tanker docks, the seawater ballast, contaminated with the small residue of oil left in the tanks after discharge, is returned to the ocean. Ordinary vessels that use oil for fuel can also produce oil slicks when waste oil or seawater ballast is dumped from their fuel tanks. This practice is illegal in most countries but the prohibitions are difficult to enforce and the legal alternative—pumping the wastes into storage tanks at port—is inconvenient and expensive.

The number of oil tankers on the world's oceans is about 4000, and the total annual transport is approaching 1 billion metric tons. The amount that is lost to the oceans accidentally or intentionally is probably less than 1%, but this still comes to several million metric tons annually. Crude oil shipping is increasing year by year and tanker sizes have increased dramatically in recent years.

Oil on water spreads rapidly into a thin layer and the lighter-molecular-weight hydrocarbons soon evaporate. The others are degraded biologically but only at a slow rate. The heavier hydrocarbons often persist for long periods of time as tarry lumps. These lumps are widely distributed on the sea surface.

The most visible effect of oil pollution is the large-scale killing of seabirds. The oil apparently penetrates the feathers, displacing the air which is normally trapped in the feathers and which provides insulation and buoyancy. The birds become colder and more susceptible to diseases and experience difficulty flying. Perhaps 100,000 birds were killed in the *Torrey Canyon* disaster; only about 100 birds survived out of the 5700 that were caught and cleaned off in an effort to save their lives.

The effects of oil on other ocean life—such as plankton—are not well-known and much more research into the long-term effects

on marine and estuarine ecosystems is needed. Some carcinogenic hydrocarbons, such as 3,4-benzpyrene have been reported in marine environments and they are occasionally concentrated by shellfish.

Oil is occasionally released by natural seepage, as George Vancouver observed off the Santa Barbara Channed. Calif., in 1793, and natural tars were used by California Indians for waterproofing of baskets. Presumably the ecosystems in which natural oil is present have adapted to its existence.

THE ENVIRONMENT (PROTECTION) ACT, 1986

No. 29 of 1986

[*23rd May, 1986*]

An Act to provide for the protection and improvement of environment and for matters connected there with.

Whereas decisions were taken at the United Nations Conference on the Human Environment held at Stockholm in June, 1972, in which India participated, to take appropriate steps for the protection and improvement of human environment ;

And whereas it is considered necessary further to implement the decisions aforesaid in so far as they relate to the protection and improvement of environment and the prevention of hazards to human beings, other living creatures, plants and property ;

Be it enacted by Parliament in the Thirty-seventh Year of the Republic of India as follows :—

CHAPTER I

Preliminary

Short title, extent and commencement.

1. (1) This Act may be called the Environment (Protection) Act, 1986.

(2) It extends to the whole of India.

(3) It shall come into force on such date as the Central Government may, by notification in the Official Gazette, appoint and different dates may be appointed for different provisions of this Act and for different areas.

Definitions.

2. In this Act, unless the context, otherwise requires,—

(*a*) "environment" includes water, air and land and the inter-relationship which exists among and between water, air and land, and human beings, other living creatures, plants, micro-organism and property ;

(*b*) "environmental pollutant" means any solid, liquid or gaseous substance present in such concentration as may be, or tend to be, injurious to environment ;

(*c*) "environmental pollution" means the presence in the environment of any environmental pollutant ;

(*d*) "handling", in relation to any substance, means the manufacture, processing, treatment, package, storage, transportation, use, collection, destruction, conversion, offering for sale, transfer or the like of such substance ;

(*e*) "hazardous substance" means any substance or preparation which, by reason of its chemical or physico-chemical properties or handling is liable to cause harm to human beings, other living creatures, plants, micro-organism, property or the environment ;

(*f*) "occupier", in relation to any factory or premises, means a person who has control over the affairs of the factory or the premises and includes, in relation to any substance, the person in possession of the substance ;

(*g*) "prescribed" means prescribed by rules made under this Act.

CHAPTER II

General powers of the General Government

Power of Central Government to take measures to protect and improve environment.

3. (1) Subject to the provisions of this Act, the Central Government shall have the power to take all such measures as it deems necessary or expendient for the purpose of protecting and improving the quality of the environment and preventing, controlling and abating environmental pollution.

(2) In particular and without prejudice to the generality of the provisions of Sub-section (1). Such measures may include measures with respect to all or any of the following matters, namely :—

(*i*) co-ordination of actions by the State Governments, officers and other authorities :—

(*a*) under this Act, or the rules made thereunder ; or

(*b*) under any other law for the time being in force which is relatable to the objects of this Act ;

(*ii*) planning and execution of a nation-wide programme for the prevention, control and abatement of environmental pollution ;

(*iii*) laying down standards for the quality of environment in its various aspects ;

(*iv*) laying down standards for emission or discharge of environmental pollutants from various sources whatsoever :

Provided that different standards for emission or discharge may be laid down under this clause from different sources having regard to the quality or composition of the emission or discharge of environmental pollutants from such sources ;

(*v*) restriction of areas in which any industries, operations or processes or class of industries, operations or processes shall not be carried out or shall be carried out subject to certain safeguards ;

(*vi*) laying down procedures and safeguards for the prevention of accidents which may cause environmental pollution and remedial measures for accidents ;

(*vii*) laying down procedures and safeguards for the handling of hazardous substances ;

(*viii*) examination of such manufacturing processes, materials and substances as are likely to cause environmental pollution ;

(*ix*) carrying out and sponsoring investigations and research relating to problems of environmental pollution :

(*x*) inspection of any premises, plant, equipment, machinery, manufacturing or other processes, materials or substances and giving,

by order, of such directions to such authorities, officers or persons as it may consider necessary to take steps for the prevention, control and abatement of environmental pollution ;

(*xi*) establishment or recognition of environmental laboratories and institutes to carry out the functions entrusted to such environmental laboratories and institutes under this Act ;

(*xii*) collection and dissemination of information in respect of matters relating to environmental pollution ;

(*xiii*) preparation of manuals, codes or guides relating to the prevention, control and abatement of environmental pollution ;

(*xiv*) such other matters as the Central Government deems necessary or expedient for the purpose of securing the effective implementation of the provisions of this Act.

(3) The Central Government may, if it considers it necessary or expedient so to do for the purposes of this Act, by order, published in the Official Gazette, constitute an authority or authorities by such name or names as may be specified in the order for the purpose of exercising and performing such of the powers and functions (including the power to issue directions under Section 5) of the Central Government under this Act and for taking measures with respect to such of the matters referred to in Sub-Section (2) as may be mentioned in the order and subject to the supervision and control of the Central Government and the provisions of such order, such authority or authorities may exercise the powers or perform the functions or take the measures so mentioned in the order as if such authority or authorities had been empowered by this Act to exercise those powers or perform those functions or take such measures.

Appointment of officers and their powers and functions.

4. (1) Without prejudice to the provisions of Sub-section (3) of section 3, the Central Government may appoint officers with such designations as it thinks fit for the purposes of this Act and may entrust to them such of the powers and functions under this Act as it may deem fit.

(2) The officers appointed under sub-section (1) shall be subject to the general control and direction of the Central Government or, if so directed by that Government, also of the authority or authorities, if any, constituted under sub-section (3) or section 3 or of any other authority or officer.

Power to give directions.

5. Notwithstanding anything contained in any other law but subject to the provisions of this Act, the Central Government may, in the exercise of its powers and performance of its functions under this Act, issue directions in writing to any person, officer or any authority and such person, officer or authority shall be bound to comply with such directions.

Explanation.—For the avoidance of doubts, it is hereby declared that the power to issue directions under this section includes the power to direct—

(*a*) the closure, prohibition or regulation of any industry, operation or process ; or

(*b*) stoppage or regulation of the supply of electricity or water or any other service.

Rules to regulate environmental pollution.

6. (1) The Central Government may, by notification in the Official Gazette, make rules in respect of all or any of the matters referred to in section 3.

(2) In particular, and without prejudice to the generality of the foregoing power, such rules may provide for all or any of the following matters, namely :

(*a*) the standards of quality of air, water or soil for, various areas and purposes ;

(*b*) the maximum allowable limits of concentration of various environmental pollutants (including noise) for different areas ;

(*c*) the procedures and safeguards for the handling of hazardous substances ;

(*d*) the prohibition and restrictions on the handling of hazardous substances in different areas ;

(*e*) the prohibition and restrictions on the location of industries and the carrying on of processes and operations in different areas ;

(*f*) the procedures and safeguards for the prevention of accidents which may cause environmental pollution and for providing for remedial measures for such accidents.

CHAPTER III

Prevention, Control and Abatement of Environmental Pollution

7. No person carrying on any industry, operation or process shall discharge or emit or permit to be discharged or emitted any environmental pollutant in excess of such standards as may be prescribed.

8. No person shall handle or cause to be handled any hazardous substance except in accordance with such procedure and after complying with such safeguards as may be prescribed.

9. (1) Where the discharge of any environmental pollutant in excess of the prescribed standards occurs or is apprehended to occur due to any accident or other unforeseen act or event, the person responsible for such discharge and the person in charge of the place at which such discharge occurs or is apprehended to occur shall be bound to prevent or mitigate the environmental pollution caused as a result of such discharge and shall also forthwith.

(*a*) intimate the fact of such occurrence or apprehension of such occurrence ; and

(*b*) be bound, if called upon, to render all assistance, to such authorities or agencies as may be prescribed.

(2) On receipt of information with respect to the fact or apprehension of any occurrence of the nature referred to in sub-section (1), whether through intimation under that sub-section or otherwise, the authorities or agencies referred to in sub-section (1) shall, as early as practicable, cause such remedial measures to

be taken as are necessary to prevent or mitigate the environmental pollution.

(3) The expenses, if any, incurred by any authority or agency with respect to the remedial measures referred to in sub-section (2), together with interest (at such reasonable rate as the Government may, by order, fix) from the date when a demand for the expenses is made until it is paid, may be recovered by such authority or agency from the person concerned as arrears of land revenue or of public demand.

Powers of entry and inspection.

10. (1) Subject to the provisions of this section, any person empowered by the Central Government in this behalf shall have a right to enter, at all reasonable times with such assistance as he considers necessary, any place—

(*a*) for the purpose of performing any of the functions of the Central Government entrusted to him ;

(*b*) for the purpose of determining whether and if so in what manner, any such functions are to be performed or whether any provisions of this Act or the rules made thereunder or any notice, order, direction or authorisation served, made, given or granted under this Act is being or has been complied with ;

(*c*) for the purpose of examining and testing any equipment, industrial plant, record, register, document or any other material object or for conducting a search of any building in which he has reason to believe that an offence under this Act or the rules made thereunder has been or is being or is about to be committed and for seizing any such equipment, industrial plant, record, register, document or other material object if he has reasons to believe that it may furnish evidence of the commission of an offence punishable under this Act or the rules made thereunder or that such seizure is necessary to prevent or mitigate environmental pollution.

(2) Every person carrying on any industry, operation or process or handling any hazardous substance shall be bound to

render all assistance to the person empowered by the Central Government under sub-section (1) for carrying out the functions under that sub-section and if he fails to do so without any reasonable cause or excuse, he shall he guilty of an offence under this Act.

(3) If any person wilfully delays or obstructs any person empowered by the Central Government under sub-section (1) in the performance of his functions, he shall be guilty of an offence under this Act.

(4) The provisions of the Code of Criminal Procedure, 1973, or, in relation to the State of Jammu and Kashmir, or any area in which that Code is not in force, the provisions of any corresponding law in force in that State or area shall, so far as may be, apply to any search or seizure under this section as they apply to any search or seizure made under the authority of a warrant issued under section 94 of the said Code or, as the case may be, under the corresponding provision of the said law.

Power to take sample and procedure to be followed in connection therewith.

11. (1) The Central Government or any officer empowered by it in this behalf, shall have power to take, for the purpose of analysis, samples of air, water, soil or other substance from any factory, premises or other place in such manner as may be prescribed.

(2) The result of any analysis of a sample taken under sub-section (1) shall not be admissible in evidence in any legal proceeding unless the provisions of sub-sections (3) and (4) are complied with.

(3) Subject to the provisions of sub-section (4), the person taking the sample under sub-section (1) shall—

(*a*) serve on the occupier or his agent or person in charge of the place, a notice, then and there, in such form as may be prescribed, of his intention to have it so analysed ;

(*b*) in the presence of the occupier or his agent of person, collect a sample for analysis ;

(*c*) cause the sample to be placed in a container or containers which shall be marked and sealed and shall also be signed both by the person taking the sample and occupier or his agent or person ;

(*d*) send without delay, the container or the containers to the laboratory established or recognised by the Central Government under section 12.

(4) When a sample is taken for analysis under sub-section (1) and person taking the sample serves on the occupier or his agent or person, a notice under clause (*a*) of sub-section (3), then—

(*a*) in a case where the occupier, his agent or person wilfully absents himself, the person taking the sample shall collect the sample for analysis to be placed in a container or containers which shall be marked and sealed and shall also be signed by the person taking the sample, and

(*b*) in a case where the occupier or his, his agent or person present at the time of taking the sample refuses to sign the marked and sealed container or containers of the sample as required under clause (*c*) of sub-section (3), the marked and sealed container or containers shall be signed by the person taking the samples, and the container or containers shall be sent without delay by the person taking the sample for analysis to the laboratory established or recognised under section 12 and such person shall inform the Government Analyst appointed or recognised under section 13 in writing, about the wilful absence of the occupier or his agent or person, as the case may be, his refusal to sign the container or containers.

Environmental laboratories.

12. (1) The Central Government may, by notification in the Official Gazette,—

(*a*) establish one or more environmental laboratories ;

(*b*) recognise one or more laboratories or institutes as environmental laboratories to carry out the functions entrusted to an environmental laboratory under this Act.

(2) The Central Government may, by notification in the Official Gazette, make rules specifying—

(*a*) the functions of the environmental laboratory ;

(*b*) the procedure for the sabmission to the said laboratory of samples of air, water, soil or other substance for analysis or tests, the form of the laboratory report thereon and the fees payable for such report ;

(*c*) such other matters as may be necessary or expedient to enable that laboratory to carry out its functions.

Government Analysis

13. The Central Government may be notification in the official Gazette, appoint or recognise such persons as it thinks fit and having the prescribed qualifications to be Government Analysts for the purpose of analysis of samples of air, water soil or other substance sent for analysis to any environmental laboratory established or recognised under sub-section (1) of section 12.

Reports of Government Analysts.

14. Any document purporting to be a report signed by a Government analyst may be used as evidence of the facts stated therein in any proceeding under this Act.

Penalty for contravention of the provisions of the Act and the rules, orders and directions.

15. (1) Whoever fails to comply with or contravenes any of the provisions of this Act, or the rules made or orders or directions issued thereunder, shall, in respect of each such failure or contravention, be punishable with imprisonment for a term which may extend to five years or with fine which may extend to one lakh rupees, or with both, and in case the failure or contravention continues, with additional fine which may extend to five thousand rupees for every day during which such failure or contravention continues after the conviction for the first such failure or contravention.

(2) If the failure or contravention referred to in sub-section (1) continues beyond a period of one year after the date of conviction, the offender shall be punishable with imprisonment for a term which may extend to seven years.

Offences by companies.

16. (1) Where any offence under this Act has been committed by a company, every person who, at the time the offence was committed, was directly in charge of, and was responsible to, the company for the conduct of the business of the company, as well as the company, shall be deemed to be guilty of the offence and shall be liable to be proceeded against and punished accordingly :

Provided that nothing contained in this sub-section shall render any such person liable to any punishment provided in this Act, if he proves that the offence was committed without his knowledge or that he exercised all due diligence to prevent the commission of such offence.

(2) Notwithstanding anything contained in sub-section (1), where an offence under this Act has been committed by a company and it is proved that the offence has been committed with the consent or connivance of, or is attributable to any neglect on the part of, any director, manager. secretary or other officer of the company, such director, manager, secretary or other officer shall also deemed to be guilty of that offence and shall be liable to be proceeded against and punished accordingly.

Explanation—For the purposes of this section,

(*a*) "company" means any body corporate and includes a firm or other association of individuals ;

(*b*) "director", in relation to a firm, means a partner in the firm.

Offences by Government Departments.

17. (1) Where an offence under this Act has been committed by any Department of Government, the Head of the Department

shall be deemed to be guilty of the offence and shall be liable to be proceeded against and punished accordingly :

Provided that nothing contained in this section shall render such Head of the Department liable to any punishment if he proves that the offence was committed without his knowledge or that he exercise all due diligence to prevent the commission of such offence.

(2) Notwithstanding anything contained in sub-section (1), where an offence under this Act has been committed by a Department of Government and it is proved that the offence has been committed with the consent or connivance of, or is attributable to any neglect on the part of, any officer, other than the Head of the Department, such officer shall also be deemed to be guilty of that offence and shall be liable to be proceeded against and punished accordingly.

CHAPTER IV
Miscellaneous

Protection of action taken in good faith.

18. No suit, prosecution or other legal proceeding shall lie against the Government or any officer or other employee of the Government or any authority constituted under this Act or any member, officer or other employee of such authority in respect of anything which is done or intended to be done in good faith in pursuance of this Act or the rules made or orders or directions issued thereunder.

Cognizance of offences.

19. No court shall take cognizance of any offence under this Act except on a complaint made by—

(*a*) the Central Government or any authority or officer authorised in this behalf by that Government ; or

(*b*) any person who has given notice of not less than sixty days, in the manner prescribed, of the alleged offence and of his

intention to make a complaint, to the Central Government or the authority or officer authorised as aforesaid.

Information, reports or returns.

20. The Central Government may, in relation to its functions under this Act, from time to time, require any person, officer, State Government or other authority to furnish to it or any prescribed authority or officer any reports, returns, statistics, accounts and other information and such person, officer, State Government or other authority shall be bound to do so.

Members, officers and employees of the authority constituted under section 3 to be public servants.

21. All the members of the authority, constituted, if any, under section 3 and all officers and other employees of such authority when acting or purporting to act in pursuance of any provisions of this Act or the pules made or orders or directions issued thereunder shall be deemed to be public servants within the meaning of section 21 of the Indian Penal Code.

Bar of jurisdiction.

22. No civil court shall have been jurisdiction to entertain any suit or proceeding in respect of anything done, action taken or order or direction issued by the Central Government or any other authority or officer in pursuance of any power conferred by or in relation to its or his functions under this Act.

Power to delegate.

23. Without prejudice to the provisions of sub-section (3) of section 3, the Central Government may, by notification in the Official Gazette, delegate, subject to such conditions and limitations as may be specified in the notification, such of its power and functions under this Act [except the power to constitute an authority under sub-section (3) of section 3 and to make rules under section 25] as it may deem necessary or expedient, to any officer, State Government or other authority.

Effect of other laws.

24. (1) Subject to the provisions of sub-section (2), the provisions of this Act and the rules or orders made therein shall have effect notwithstanding anything inconsistent therewith contained in any enactment other than this Act.

(2) Where any act or omission constitutes an offence punishable under this Act and also under any other Act then the offender found guilty of such offence shall be liable to be punished under the other Act and not under this Act.

Power to make rules.

25. (1) The Central Government may, by notification in the Official Gazette, make rules for carrying out the purposes of this Act.

(2) In particular, and without prejudice to the generality of the foregoing power, such rules may provide for all or any of the following matters, namely :—

(*a*) the standards in excess of which environmental pollutants shall not be discharged or emitted under section 7 ;

(*b*) the procedure in accordance with and the safeguards in compliance with which hazardous substances shall be handled or cause to be handled under section 8 ;

(*c*) the authorities or agencies to which intimation of the fact of occurrence or apprehension of occurrence of the discharge of any environmental pollutant in excess of the prescribed standards shall be given and to whom all assistance shall be bound to be rendered under sub-section (1) or section 9 ;

(*d*) the manner in which samples of air, water, soil or other substance for the purpose of analysis shall be taken under sub-section (1) of section 11 ;

(*e*) the form in which notice of intention to have a sample analysed shall be served under clause (*a*) of sub-section (3) of section 11 ;

(*f*) the functions of the environmental laboratories, the procedure for the submission to such laboratories of samples of air, water, soil and other substances for analysis or test ; the form of laboratory report ; the fees payable for such report and other matters to enable such laboratories to carry out their functions under sub-section (2) of section 12 ;

(*g*) the qualifications of Government Analyst appointed or recognised for the purpose of analysis of samples of air, water, soil or other substances under section 13 ;

(*h*) the manner in which notice of the offence and of the intention to make a complaint to the Central Government shall be given under clause (*b*) of section 19 :

(*i*) the authority or officer to whom any reports, returns, statistics, accounts and other information shall be furnished under section 20 ;

(*j*) any other matter which is required to be, or may be, prescribed.

Rules made under this Act to be laid before Parliament.

26. Every rule made under this Act shall be laid, as soon as may be after it is made, before each House of Parliament, while it is in session, for a total period of thirty days which may be comprised in on session or in two or more successive sessions, and if, before the expiry of the session immediately following the session or the successive sessions aforesaid, both Houses agree in making any modification in the rule or both Houses agree that the rule should not be made, the rule shall thereafter have effect only in such modified form or be of no effect, as the case may be ; so, however, that any such modification or annulment shall be without prejudice to the validity of anything previously done under that rule.

C. RAMAN MENON,

Additional Secy. to the Govt. of India.

MINISTRY OF ENVIRONMENT & FORESTS

(Department of Environment, Forests & Wildlife)

New Delhi, the 19th November, 1986

NOTIFICATION

S.O. 844(E).—In exercise of the powers conferred by sections 6 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules, namely :

1. Short title and commencement :—

   (*i*) These rules may be called the Environment (Protection) Rules, 1986.

   (*ii*) They shall come into force on the date of their publication in the Official Gazette.

2. Definitions :—In these rules, unless the context otherwise requires,—

   (*a*) "Act" means the Environment (Protection) Act, 1986 (29 of 1986) ;

   (*b*) "Central Board" means the Central Board for the Prevention and Control of Water Pollution constituted under section 3 of the Water (Prevention and Control of Pollution) Act, 1974 (6 of 1974) ;

   (*c*) "Form" means a form set forth in Appendix A to these rules ;

   (*d*) "Government Analyst" means a person appointed or recognized as such under Section 13 ;

   (*e*) "Person" in relation to any factory or permises means a person or occupier or his agent who has control over the affairs of the factory or premises and includes in relation to any substance, the person in possession of the substance ;

(*f*) "Recipient system" means the part of the environment such as soil, water, air or other which receives the pollutants ;

(*g*) "Section" means a section of the Act ;

(*h*) "Schedule" means a Schedule appended these rules ;

(*i*) "Standards" means standards prescribed under these rules ;

(*j*) "State Board" means a State Board for the Prevention and Control of Water Pollution Constituted under section 4 of the Water (Prevention and Control of Water Pollution) Act, 1974 (6 of 1974) or a State Board for the Prevention and Control of Air Pollution constituted under section 5 of the Air (Prevention and Control of Pollution) Act, 1981 (14 of 1981) ;

3. Standards for emission or discharge of environmental pollutants :

(1) For the purposes of protecting and improving the quality of the environment and preventing and abating environmental pollution, the Standards for emission or discharge of environmental pollutants from the industries, operations or processes shall be as specified in the Schedule :

Provided where an industry, operation or process has been granted time by the Central Board or a State Board to implement a time bound programme to treat the environmental pollutants so as to bring them to the standards prescribed under these rules after specifying certain conditions and where such an industry, operation or process by adhering strictly to such stipulations specified by the Central or the State Board discharges environmental pollutants in excess of the prescribed standards during such period of such time-bound programme, such discharge shall not be considered as an offence under the Act.

(2) Notwithstanding anything contained in sub-rule (1), the Central Board or a State Board may specify more stringent standards from those provided in the Schedule in respect of any specific industry, operation or process depending upon the quality of the recipient system and after recording reasons therefore in writing.

4. Directions :

(1) Any direction issued under section 5 shall be in writing.

(2) The direction shall specify the nature of action to be taken and the time within which it shall be complied with by the person, officer or the authority to whom such direction is given.

(3) The person, officer or authority to whom any direction is sought to be issued shall be served with a copy of the proposed direction and shall be given an opportunity of not less than fifteen days from the date of service of a notice to file with an officer designated in this behalf the objections, if any, to the issue of the proposed direction.

(4) The Central Government shall within a period of 45 days from the date of receipt of the objections, if any, or from the date upto which an opportunity is given to the person, officer or authority to file objections whichever is earlier, after considering the objections, if any, received from the person, officer or authority sought to be directed and for reasons to be recorded in writing, confirm, modify or decide not to issue the proposed direction.

(5) In a case where the Central Government is of the opinion that in view of the likelihood of a grave injury to the environment it is not expedient to provide an opportunity to file objections against the proposed

direction, it may, for reasons to be recorded in writing, issue directions without providing such an opportunity.

(6) Every notice or direction required to be issued under this rule shall be deemed to be duly served—

(*a*) where the person to be served is a company, if the document is addressed in the name of the company at its registered office or at its principal office or place of business and is either—

(*i*) sent by registered post, or

(*ii*) delivered at its registered office or at the principal office or place of business ;

(*b*) where the person to be served is an officer serving Government, if the document is addressed to the person and a copy thereof is endorsed to this Head of the Department and also to the Secretary to the Government, as the case may be, incharge of the Department in which for the time being the business relating to the Department in which the officer is employed is transacted and is either—

(*i*) sent by registered post, or

(*ii*) is given or tendered to him ;

(*c*) in any other case, if the document is addressed to the person to be served and—

(*i*) is given or tendered to him, or

(*ii*) if such person cannot be found, is affixed on some conspicuous part of his last known place of residence or business or is given or tendered to some adult member of his family or is affixed on some conspicuous part of the land or building, if any, to which if relates, or

(*iii*) is sent by registered post to that person.

Explanation :—For the purposes of this sub-rule,—

(*a*) "company" means any body corporate and includes a firm or other association of individuals ;

(*b*) "a servant" is not a member of the family.

5. Prohibition and restriction on the location of industries and the carrying on processes and operations in different areas.

(1) The Central Government may take into consideration the following factors while prohibiting or restricting the location of industries and carrying on of processes and operations in different areas :—

(*i*) Standards for quality of environment in its various aspects laid down for an area.

(*ii*) The maximum allowable limits of concentration of various environmental pollutants (including noise) for an area.

(*iii*) The likely emission or discharge of environmental pollutants from an industry, process or operation proposed to be prohibited or restricted.

(*iv*) The topographic and climatic features of an area.

(*v*) The biological diversity of the area which, in the opinion of the Central Government needs to be preserved.

(*vi*) Environmentally compatible land use.

(*vii*) Net adverse environmental impact likely to be caused by an industry, process or operation proposed to be prohibited or restricted.

(*viii*) Proximity to a protected area under the Ancient Monuments and Archaeological Sites and Remains Act, 1958 or a sanctuary, National Park, game reserve or closed area notified as such under the Wild Life (Protection) Act, 1972 or places protected under any treaty, agreement or convention with any other country or countries

or in pursuance of any decision made in any international conference, association or other body.

(*ix*) Proximity to human settlements.

(*x*) Any other factor as may be considered by the Central Government to be relevant to the protection of the environment in an area.

(2) While prohibiting or restricting the location of industries and carrying on of processes and operations in an area, the Central Government shall follow the procedure hereinafter laid down.

(3) (*a*) Whenever it appears to the Central Government that it is expedient to impose prohibition or restrictions on the location of an industry or the carrying on of processes and operations in an area, it may, by notification in the Official Gazette and in such other manner as the Central Government may deem necessary from time to time, give notice of its intention to do so.

(*b*) Every notification under clause (*a*) shall give a brief description of the area, the industries, operations, processes in that area about which such notification pertains and also specify the reasons for the imposition of prohibition or restrictions on the location of the industries and carrying on processes or operations in that area.

(*c*) Any person interested in filing an objection against the imposition of prohibition or restrictions on carrying on of processes or operations as notified under clause (*a*) may do so in writing to the Central Government within sixty days from the date of publication of the notification in the Official Gazette.

(*d*) The Central Government shall within a period of one hundred and twenty days from the date of publication of the notification in the Official

Gazette consider all the objections received against such notification and may impose prohibition or restrictions on location of such industries and the carrying on of any process or operation in an area.

6. Procedure for taking samples :

The Central Government or the officer empowered to take samples under Section 11 shall collect the sample in sufficient quantity to be divided into three uniform parts and effectively seal and suitably mark the same and permit the person from whom the sample is taken to add his own seal or mark to all or any of the portions so sealed and marked. In case where the sample is made up in containers of small volumes and is likely to deteriorate or be otherwise damaged if exposed, the Central Government or the officer empowered shall take three of the said samples without opening the containers and suitably sea and mark the same. The Central Government or the officer empowered shall dispose of the samples so collected as follows :—

(*i*) One portion shall be handed over to the person from whom the sample is taken under acknowledgement ;

(*ii*) The other portion shall be sent forthwith to the environmental laboratory for analysis ; and

(*iii*) The last portion shall be retained by him to be produced in the Court before which proceedings, if any, are instituted.

7. Service of notice :

The Central Government or the officer empowered shall serve on the occupier or his agent or person in charge of the place a notice then and there in Form I of his intention to have the sample analysed.

8. Procedure for submission of samples for analysis, and the form of laboratory report thereon :

(1) Sample taken for analysis shall be sent by the Central Government or the officer empowered to the environmental laboratory by registered post or through special messenger along with Form II.

(2) Another copy of Form II together with specimen impression of seats of the officer empowered to take samples along with the seals/marks, if any, of the person from whom the sample is taken shall be sent separately in a sealed cover by registered post or through a special messenger to the environmental laboratory.

(3) The findings shall be recorded in Form III in triplicate and signed by the Government Analyst and sent to the officer from whom the sample is received for analysis.

(4) On receipt of the report of the findings of the Government Analyst, the officer shall send one copy of the report to the person from whom the sample was taken for analysis, the second copy shall be retained by him for his records and the third copy shall be kept by him to be produced in the Court before which proceedings, if any, are instituted.

9. Functions of environmental laboratories :

The following shall be the functions of environmental laboratories :—

(*i*) to evolve standardised methods for sampling and analysis of various types of environmental pollutants ;

(*ii*) to analyse samples sent by the Central Government or the officers empowered under sub-section (1) of section 11.

(*iii*) to carry out such investigations as may be directed by the Central Government to lay down standards for the quality of environment and discharge of environmental pollutants, to monitor and to enforce the standards laid down ;

(*iv*) to send periodical reports regarding its activities to the Central Government ;

(*v*) to carry out such other functions as may be entrusted to it by the Central Government from time to time.

10. Qualifications of Government Analyst :

A person shall not be qualified for appointment or recognised as a Government Analyst unless he is a :—

(*a*) graduate in science from a recognised university with five years experience in a laboratory engaged in environmental investigations, testing or analysis ; or

(*b*) post-graduate in science or a graduate in engineering or a graduate in medicine or equivalent with two years experience in a laboratory engaged in environmental investigations, testing or analysis ; or

(*c*) post-graduate in environmental science from a recognized university with two years experience in a laboratory engaged in environmental investigations, testing or analysis.

11. Manner of giving notice :

The manner of giving notice under clause (*b*) of section 19 shall be as follows, namely :—

(1) The notice shall be in writing in Form IV.

(2) The person giving notice may send notice to :—

(*a*) if the alleged offence has taken place in a Union territory :—

(*A*) the Central Board ; and

(*B*) Ministry of Environment and Forests (represented by the Secretary to the Government of India) ;

(*b*) if the alleged offence has taken place in a State :—

(*A*) the State Board ; and

(*B*) the Government of the State (represented by the Secretary to the State Government incharge of environment) ; and

(*C*) the Ministry of Environment and Forests (represented by the Secretary to the Government of India) ;

(3) The notice shall be sent by registered post acknowledgement due ; and

(4) The period of sixty days mentioned in clause (*b*) of section 19 of the Environment (Protection) Act, 1986 shall be reckoned from the date it is first received by one of the authorities mentioned above.

SCHEDULE

(See rule 3)

Ser. No.	*Industry*	*Parameter*	*Standards*
1	2	3	4
1.	Caustic Soda Industry		Concentration not to exceed, milligramme per litre (except for pH and flow)
		Total concentration of mercury in the final effluent*	0.01
		Mercury bearing waste-water generation (flow)	10 kilolitres/tonne of caustic soda produced
		pH	5.5 to 9.0
		*Final effluent is the combined effluent from (*a*) cell house, (*b*) brine plant, (*c*) chlorine handling, (*d*) hydrogen handling, (*e*) hydrochloric acid plant.	
2.	Man-made fibres (synthetic)		Concentration not to exceed milligramme per litre (except for pH)
		Suspended solids	100
		Bio-chemical oxygen demand, 5 day 20°C 30	
		pH	5.5 to 9.0

(1)	(2)	(3)	(4)	
3.	Oil refinery industry	Concentration, not to exceed, milligramme per litre (except for pH)	Quantum, kg/1000 tonnes crude processed.	
		Oil and grease	10	7
		Phenol	1	0.7
		Sulphide	0.5	0.35
		Bio-chemical oxygen demand, 5 day 20°C	15	10.5
		suspended solids	20	14
		pH	6 to 8.5	
4.	Sugar industry		Concentration not exceed, milligramme per liter	
		Bio-chemical oxygen demand, 5 day 20°C	100 for disposal on land 30 for disposal in surface waters	
		Suspended solids	100 for disposal on land 30 for disposal in surface waters.	

(1)	(2)	(3)	(4)
5.	Thermal power plants		Maximum limiting concentration, milligramme per litre (except for pH and temperature)
	Condenser cooling waters (once through cooling system)	pH	6.5—8.5
		Temperature	Not more than 5°C higher than the intake water temperature.
		Free available chlorine	0.5
	Boiler blowdowns	Suspended solids	100
		Oil and grease	20
		Copper (total)	1.0
		Iron (total)	1.0
	Cooling tower blowdown	Free available chlorine	0.5
		Zinc	1.0
		Chromium (total)	0.2
		Phosphate	5.0
		Other corrosion inhibiting material	Limit to be established on case by case basis by Central Board in case of Union territories and State Boards in case of States
	Ash pond effluent	pH	6.5—8.5
		Suspended solids	100
		Oil and grease	20

(1)	(2)	(3)	(4)
6.	Cotton textile industries (composite and processing)		Concentration not to exceed, milli-gramme per liter (except for pH and bio-assay)
		Common	
		pH	5.5 to 9
		Suspended solids	100
		Bio-chemical oxygen demand, 5 day 20°C	150
		Oil and grease	10
		Bio-assay test	90% survival of fish of after 96 hours
		Special :	
		Total chromium (as Cr)	2
		Sulphide (as S)	2
		Phenolic compounds (as C_6H_5OH)	5

The special parameters are to be stipulated by the Central Board in case of Union territories and State Boards in case of States depending upon the dye used in the industry. Where the industry uses chrome dyes, sulphur dyes and/or phenolic compounds in the dyeing/printing process, the limits on chromium of 2 mg/litres, sulphides of 2 mg/litre and phenolic compounds of 5 mg/litre respectively shall be imposed.

(1)	(2)	(3)	(4)

Where the quality requirement of the recipient system so warrants, the limit of BOD should be lowered upto 30 according to the requirement by the State Boards for the States and the Central Board for the Union territories.

A limit on sodium absorption ratio of 26 should be imposed by the State Boards forth States and the Central Board for the Union territories if the disposal of effluent is to be made on land.

(1)	(2)	(3)	(4)
7.	Composite woollen mills		Concentration not to exceed, milligramme per litre (except for pH and bio-assay)
	Common :		
		Suspended solids	100
		pH	5.5 to 9.0
		Bio-chemical oxygen demand, 5 day 20°C	100
		Oil and grease	10
		Bio-assay	90% survival of fish after 96 hours
	Special :		
		Total chromium (as Cr)	2
		Sulphide (as S)	2
		Phenolic compounds (as C_6H_5OH)	5

The special parameters are to be stipulated by the Central Board in case of Union territories and State Boards in case of States depending upon the dye used in the industry. Where the industry uses chrome dyes, sulphur dyes and/or phenolic compounds in the dyeing/printing process, the limits on thromium of 2 mg/litre, sulphide of 2 mg/litre and phenolic compounds of 5 mg/litre respectively shall be impoced.

Where the quality requirement of the recipient system so warrants, the limit of BOD should be lowered upto 30 according to the requirement by the State Boards for the States and the Central Board for the Union territories.

A limit on sodium absorption ratio of 26 should be imposed by the State Boards for the States and the Central Board for the Union territories if the disposal of effluent is to be made on land.

APPENDIX A

FORM I

(See rule 7)

Notice of intention to have sample analysed

To

....

....

Take notice that it is intended to have analysed the sample of ....which has been taken today, the......

.... day of... . . . .

19... . . . . . . from. . . . .

... .

(Name and designation of the person who takes the sample)

*specify the place from where the sample is taken,
(SEAL)
Date......

FORM II

(See rule 8)

MEMORANDUM TO GOVERNMENT ANALYST

From

... .

... .

To

The Government Analyst

... .

... .

The portion of sample described below is sent herewith for analysis under rule 6 of the Environment (Protection) Rules, 1986. The portion of sample has been marked by me with the following mark :

Details of the portion of sample taken.

Name and designation of person who sends sample

Date... (SEAL)

FORM III

(See rule 8)

REPORT BY GOVERNMENT ANALYST

Report No....

Date...

I hereby certify that I...

Government Analyst duly appointed under section 13 of the Environment (Protection) Act, 1986 received on the...

. . . day of... . . . . 19... . .

from...

*...

a sample of... for analysis.

The sample was in a condition fit for analysis as reported below.

I further certify that I have analysed the aforementioned sample on... ...and declare the result of the analysis to be as follows :

**... . . . .

... .

The condition of seals, fastening of sample on receipt was as follows :

... .

... .

Signed this... day of...

19...

Address... Signature

(Government Analyst)

To

... .

... .

... .

*Here write the name of the officer/authority from whom sample was obtained.

**Here write full details of analysis and refer to method of analysis.

FORM IV

(See rule 11)

FORM OF NOTICE

By registered post acknowledgement due

Form (1)

Shri...

. . . . .

. . . . .

To

. . . . .

. . . . .

Notice Under Section 19 (*b*) of the Environment (Protection) Act, 1986

Whereas an offence under the Environment (Protection) Act, 1986 has been committed/is being committed by. . . . .

.... (2)

I/we hereby give notice of 60 days under section 19 (*b*) of the Environment (Protection) Act, 1986 of my/our intention to file a complaint in the court against...... ....(2) for violation of section of the Environment (Protection) Act, 1986.

I support of my/our notice, I am/we are enclosing the following documents (3) as evidence of proof of violation of the Environment (Protection) Act, 1986.

Place. . . . . Signature(s)

Dated . . . .

Explanation :

(1) In case the notice is given in the name of a company, documentary evidence authorising the person to sign the notice on behalf of the company shall be enclosed to this notice.

Company for this purpose means a company defined in explanation to sub-rule (6) or rule 4.

(2) Here give the name and address of the alleged offender. In case of a manufacturing/processing/operating unit, indicate the name/location/nature of activity, etc.

(3) Documentary evidence shall include photographs/technical reports/thealth reports of he area, etc., for enabling enquiry into the alleged violation/offence.

(No. 1 (18)/86-PL)
T.N. SESHAN, Secy.

MINISTRY OF ENVIRONMENT AND FORESTS
(Department of Environment, Forests and Wildlife)

NOTIFICATIONS

New Delhi, 16th February, 1987

S.O. 82 (E).—In exercise of the powers conferred by section 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely :—

1. (*i*) These rules may be called the Environment (Protection) Amendment Rules, 1987.

(*ii*) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986 (hereinafter referred to as the principal rules), after rule 11, the following shall be inserted, namely :—

"12. Furnishing of Information to authorities and agencies in certain cases :—

Where the discharge of environmental pollutant in excess of the prescribed standards occurs or is apprehended to occur due to

any accident or other unforseen a torevent, the person in charge of the place at which such discharges occurs or it apprehended to occur shall forth intimate the fact of such occurence or apprehension of such occurence to all the following authorities or agencies, namely :—

(*i*) The officer-in-charge of emergency or disaster relief operations in a district or other region a state of Union territory specified by whatever designation, by the Government of the said State or Union territory, and in whose jurisdiction the industry, process or operation is located.

(*ii*) Central Board or a State Board, as the case may be and its regional officer having local jurisdiction who have been delegated powers under sections 20, 21, 23 of the Water (Prevention and Control of Pollution) Act, 1974 (6 of 1974) and section 24 of the Air (Prevention and Control of Pollution) Act, 1981 (14 of 1981).

(*iii*) The statutory authorities or agencies specified in column 3 in relation to places mentioned in column 2 against thereof of the Schedule II".

3. Schedule to the principal rules shall be renumbered as Schedule (1).

4. After Schedule I, as so renumbered, the following shall be inserted, namely :—

SCHEDULE II

(See Rule 12)

Sl. No.	Place at which the discharge of any environmental pollutant in excess of prescribed standards occurs or is apprehended to occur	Authorities or agencies to be intimated	Appointed under
1	2	3	4
1	Factories as defined under the Factories Act, 1948—		

1	2	3	4
	(*a*) owned by Central Government and engaged in carrying out the purposes of the Atomic Energy Act, 1962 ;	(*i*) The Atomic Energy Regulatory Board (AERB)	The Atomic Energy Act, 1962
		(*ii*) The Ministry of environment and Forests.	—
	(*b*) Factories other than those mentioned in paragraph (a)	(*i*) The Chief Inspector of Factories.	The Factories Act, 1984.
		(*ii*) The Inspector of Factories having local jurisdiction.	-do-
		(*iii*) The Ministry of Environment and Forests.	—
2.	Mine as defined under the Mines and Minerals (Regulation and Development) Act, 1957.	(*i*) The Controller General of Indian Bureau of Mines.	The Mines and Mineral (Regulation & Development) Act, 1957.
		(*ii*) Deputy Controller of Mines having local jurisdiction.	-do-
		(*iii*) The Ministry of Environment and Forests.	.

1	2	3	4
3.	Port as defined under the Indian Ports Act, 1908.	(*i*) Conservator of Ports	The Indian Ports Act, 1908.
		(*ii*) The Minisry of Environment and Forests.	—
4.	Plantation as defined under the plantations Labour Act, 1951.	(*i*) The Chief Inspector of Plantations.	The Plantactions Labour Act, 1951.
		(*ii*) The Inspector of Plantations having local jurisdiction.	-do-
		(*iii*) The Ministry of Environment and Forests.	—
5.	Motor Vehicle as defined under the Motor Vehicles Act, 1939.	(*i*) State Transport Authority	The Motor Vehicles Act, 1939.
		(*ii*) Regional Transport Authority having regional jurisdiction.	-do-
		(*iii*) The Ministry of Environment and Forests.	—
6.	Ship as defined under the Merchant Shipping Act, 1958.	(*i*) Director General of Shipping.	The Merchant Shipping Act, 1958.

(*ii*)	Surveyor having jurisdiction.	-do-
(*iii*)	The Ministry of Environment and Forests.	—

S.O. 83(E).—In exercise of the powers conferred under sub-section (1) of section 10, the Central Government hereby empowers the persons listed in the Table here below for the purposes of that sub-section.

TABLE

Sl. No.	*Officer/Agency*	*Appointed under*
1.	Director General, Factory Advice Service and Labour Institute.	Dock Workers (Safety, Health and Welfare) Act, 1986.
2.	Deputy Director General Factory Advice Service & Labour Institute.	-do-
3.	Director (Dock Safety).	-do-
4.	Joint Director (Dock Safety).	-do-
5.	Deputy Director (Dock Safety).	-do-
6.	Assistant Director (Dock Safety).	-do-
7.	Additional Assistant Director (Dock Safety).	-do-
8.	Chief Inspector of Factories	The Factories Act, 1948
9.	Additional Chief Inspector of Factories.	-do-
10.	Joint Chief Inspector of Factories.	-do-
11.	Deputy Chief Inspector of Factories.	The Factories Act, 1948

	2	3
12.	Inspector of Factories.	-do-
13.	Controller General of Indian Bureau of Mines	The Mines & Mineral (Regulation & Development) Act, 1957.
14.	Chief Controller of Mines.	-do-
15.	Controller of Mines	-do-
16.	Regional Controller of Mines.	-do-
17.	Deputy Controller of Mines.	-do-
18.	Port Authority	The Dock Workers Safety Health & Welfare Scheme 1961 and Dock Workers Advisory Committee Rules.
19.	Inspector	-do-
20.	Chief Inspector of Plantation	The Plantation Labour Act, 1951.
21.	Inspector	-do-
22.	Inspector of Dock Safety	The Indian Dock Labourers Act, 1934.
23.	Conservator of Ports	The Indian Port Act, 1908.
24.	Deputy Conservator of Ports	The Indian Port Act, 1908.
25.	Harbour Master	-do-
26.	Director (Marine Department)	The Merchant Shipping Act, 1958.
27.	Manager (Marine Operation)	-do-
28.	Director (Pollution Control)	-do-
29.	State Board for the Prevention and Control of Water Pollution and the officers empowered by State Board under section 21 and 23 of the Water (Prevention and Contrel of Pollution) Act, 1974 or under section 24 of the Air (Prevention and	The Water (Prevention and Control of Pollution) Act, 1974 and rules made thereunder. The Air Prevention and Control of Pollution) Act, 1981.

1	2	3
	Control of Pollution) Act, 1981.	
30.	Central Board for the Prevention and Control of Water Pollution and any officer empowered by the Board under section 23 of the Water (Prevention and Control of Pollution) Act, 1974 or under section 24 of the (Prevention and Control of Pollution) Act, 1981.	The Air (Prevention and Control of Pollution) Act, 1981 or the Water (Prevention and Control of Pollution) Act, 1974 and the rules made thereunder.
31.	State Transport Authority	The Motor Vehicles Act, 1939.
32.	Regional Transport Authority	-do-
33.	Any other authority or person delegated with powers by the State Transport Authority under the provisions of section 44(5) of the Motor Vehicles Act, 1939.	-do-
34.	Food (Health) Authorities in the State/Union territory or such other subordinate or local authorities as may be specified under the provisions of the Prevention of Food Adulteration Act, 1955 for the time being.	The Prevention of Food Adulteration Act, 1955 and Rules made thereunder,
35.	Food Inspector	The Prevention of Food Adulteration Act, 1955 and Rules made thereunder.

1	2	3
36.	The Atomic Energy Regulatory Board.	The Atomic Energy Act, 1972.
37.	Drug Controller of India	The Drugs & Cosmetics Act, 1940.
38.	Commissioner for Food and Drug Administration or any authority in charge of a State Drug Control Administration.	The Drugs & Cosmetics Act, 1940.
39.	Drug Inspector	-do-
40.	Chief Controller of Explosives	The Explosives Act, 1984 and The Explosives Rules, 1983.
41.	Joint Chief Controller of Explosives	-do- -do-
42.	Deputy Chief Controller of Explosives.	-do-
43.	Controller of Explosives	-do-
44.	Licensing Officer	The Insecticides Act, 1968.
45.	Insecticides Inspector	-do-
46.	Chief Controller of Explosives	The Petroleum Act, 1934.
47.	Deputy Chief Controller of Explosives	-do-
48.	Controller of Explosives	-do-
49.	Deputy Controller of Explosives.	-do-
50.	Assistant Controller of Explosives.	-do-
51.	Inspector	-do-
52.	Chief Inspector of Boilers	The India Boilers Act, 1923.
53.	Deputy Chief Inspector of Boilers.	-do-
54.	Inspector of Boilers	-do-

1	2	3
55.	Director General of Shipping	Merchant Shipping Act, 1958.
56.	Surveyor	-do-
57.	Director General (TD) or his nominee not below the rank of Development Officer.	Industrial (Development and Regulation) Act, 1951.
58.	Chairman & Director General, National Council for Cement and Building Materials or his nominee not below the rank of Programme leader.	-do-
59.	Officers appointed under The Bengal Smoke Nuisance Act, 1905.	The Bnegal Smoke Nuisance Act, 1905.
	The Bombay Smoke Nuisance Act. 1982 and The Gujarat Smoke Nuisance Act, 1963.	The Bombay Smoke Nuisance Act, 1912 and The Gujarat Smoke Nuisance Act, 1963.

S.O. 84(E).—In exercise of the powers conferred under sub-section (*i*) of Section 11, the Central Government hereby empowers the person listed in the Table here below for the purpose of that sub-section.

TABLE

Sl. No.	*Officer/Agency*	*Appointed under*
	2	3
1.	Director General Factory Advice Service and Labour Institute.	Dock Workers (Safety, Health and Welfare) Act, 1986.
2.	Deputy Director General, Factory Advice Service & Labour Institute.	Dock Workers (Safety Health and Welfare) Act, 1986.

1	2	3
3.	Director (Dock Safety)	-do-
4.	Joint Director (Dock Safsty)	-do-
5.	Deputy Director (Dock Safety)	-do-
6.	Assistant Director (Dock Safety)	-do-
7.	Additional Assistant Director (Dock Safety)	-do-
8.	Chief Inspector of Factories	The Factories Act, 1948.
9.	Additional Chief Inspector of Factories.	-do-
10.	Joint Chief Inspector of Factories.	-do-
11.	Deputy Chief Inspector of Factories.	-do-
12.	Inspector of Factories	-do-
13.	Controller General of Indian Bureau of Mines.	The Mines & Mineral (Regulation & Development) Act, 1957.
14.	Chief Controller of Mines	-do-
15.	Controller of Mines	-do-
16.	Regional Controller of Mines	-do-
17.	Deputy Controller of Mines	-do-
18.	Port Authority	The Dock Workers (Safety Health & Welfare) Scheme, 1961 and Dock Workers Advisory Committee Rules.
19.	Inspector	-do-
20.	Chief Inspector of Plantation	The Plantation Labour Act, 1951.
21.	Inspector	-do-
22.	Inspector of Dock Safety	The Indian Dock Labourers Act, 1934.
23.	Conservator of Ports	The Indian Port Act, 1908.

1		
24.	Deputy Conservator of Ports	-do-
25.	Harbour Master	-do-
26.	Director (Marine Department)	The Merchant Shipping Act, 1958.
27.	Manager (Marine Operation)	-do-
28.	Director (Pollution Control)	-do-
29.	State Board for the Prevention and Control of Water Pollution and the officers empowered by State Board under section 21 and 23 of the Water Prevention and (Control of Pollution) Act, 1974 or under section 24 of the Air (Prevention and Control of Pollution) Act, 1981.	The Water (Prevention and Control of Pollution) Act, 1974 and rules made thereunder. The Air (Prevention and Control of Pollution) Act, 1981.
30.	Central Board for the Prevention and Control of Water Pollution and any officer empowered by the Board under section 23 of the Water (Prevention and Control of Pollution) Act, 1974 or under section 24 of the Air (Prevention and Control of Pollution) Act, 1981.	The Air (Prevention and Control of Pollution) Act, 1981 or the Water (Prevention and Control of Pollution) Act, 1974 and the rules made thereunder.
31.	State Transport Authority	The Motor Vehicles Act, 1939.
32.	Regional Transports Authority	-do-
33.	Any other authority or person delegated with powers by the State Transport Authority under the provisions of section 44 (5) of the Motor Vehicles Act, 1939.	-do-

1	2	3
34.	Food (Health) Authorities in the State Union territory or such other subordinate or local authorities as may be specified under the provisions of the Prevention of Food Adulteration Act, 1955 for the time being.	The Prevention of Food Adulteration Act, 1955 and Rules made thereunder.
35.	Food Inspector	The Prevention of Food Adulteration Act, 1955 and Rules made thereunder.
36.	The Atomic Energy Regulatory Board	The Atomic Energy Act, 1972.
37.	Drug Controller of India	The Drugs & Cosmetics Act, 1940.
38.	Commissioner or Food and Drug Administration of any authority in charge of a State Drug Control Administration.	The Drugs & Cosmetics Act, 1940.
39.	Drug Inspector	-do-
40.	Chief Controller of Explosives	The Explosives Act 1984 and The Explosive Rules, 1983.
41.	Joint Chief Controller of Explosives	-do-
42.	Deputy Chief Controller of Explosives	-do-
43.	Controller of Explosives	-do-
44.	Licensing Officer	The Insecticides Act, 1968.
45.	Insecticides Inspector	-do-
46.	Chief Controller of Explosives	The Petroleum Act, 1934.
47.	Deputy Chief Controller of Explosives	-do-

1	2	3
48.	Controller of Explosives	-do-
49.	Deputy Controller of Explosives	-do-
50.	Assistant Controller of Explosives	-do-
51.	Inspector	-do-
52.	Chief Inspector of Boilers	The Indian Boilers Act, 1923.
53.	Deputy Chief Inspector of Boilers	-do-
54.	Inspector of Boilers	-do-
55.	Director General of Shipping	Merchant Shipping Act, 1958.
56.	Surveyor	-do-
57.	Director General (TD) or its nominee not below the rank of Development Officer.	Industral (Development and Regulation) Act, 1951.
58.	Chairman & Director General, National Council for Cement and Building Materials or his nominee not below the rank of Programme leader.	-do-
59.	Officers appointed under The Bengal Smoke Nuisance Act, 1905.	The Bengal Smoke Nuisance Act, 1905.
	The Bombay Smoke Nuisance Act, 1912 and	The Bombay Smoke Nuisance Act, 1912 and
	The Gujarat Smoke Nuisance Act, 1963.	The Gujarat Smoke Nuisance Act, 1963.

[No. 1(18)86—PL]
T.N. SESHAN, Secy.

MINISTRY OF ENVIRONMENT AND FORESTS

(Department of Environment, Forests & Wildlife)
New Delhi, the 16th April, 1987

NOTIFICATIONS

S.O. No. 393(E)—In exercise of the powers conferred by section 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely :—

1. (*i*) These rules may be called the Environment (Protection) Second Amendment Rules, 1987.

(*ii*) They shall come into force on the date of their publication in the Official Gazette.

2. In the Schedule to the Environment (Protection) Rules, 1986, after serial number 7, the following shall be inserted namely :—

1	2	3	4
8.	Dye and Dye Intermediate Industries.		Concentration not to exceed milligrammes per litre (except for pH, temperature and bio-assay)
		Suspended Solids	100
		pH	6 to 8.5
		Temperature	Shall not exceed 5°C above the ambient temperature of the receiving body.
		Mercury (As Hg)	0.01
		Hexavalent (As Cr) Chromium	0.1

1	2	3	4
		Total Chromium (as Cr)	2.0
		Copper (as Cu)	3 0
		Zinc (as Zn)	5.0
		Nickel (as Ni)	3.0
		Cadmium (as Cd)	2.0
		Chloride (as Cl)	1000
		Sulphate (as SO_4)	1000
		Phenolic Compounds (as C_6H_5OH)	1.0
		Oil and Grease	10
		Bio-assay Test (with 1 : 8 dilution of effluents)	90% Surival of Test animals after 96 hours.

The standards for chlorides and sulphates are applicable or discharge into inland and surface water courses. However, when discharged on land for irrigation, the limit for chloride shall not be more than 600 milligrammes per litre and the sodium absorption ratio shall not exceed 26.

9.	Electroplating Industries		Concentration not to exceed milligerammes per litre (except for pH and temperature)
		pH	6.0 to 9.0
		Temperature	shall not exceed 5°C above the ambient temperature of the receiving body.
		Oil and Grease	10
		Suspended Solids	100
		Cyanides (as CN)	0.2

	Ammonical Nitrogen (as N)	50
	Total Residual Chloride (as Cl)	1.0
	Cadmium (as Cd)	2.0
	Nickel (as Ni)	3.0
	Zinc (As Zn)	5.0
	Hexavalent Chromium (as Cr)	0.1
	Total Chromium (As Cr)	2.0
	Copper (As Cu)	3.0
	Lead (As Pb)	0.1
	Iron (As Fe)	3.0
	Total Metal	10.0
10. Cement Plants Plant Capacity	Total dust	Not to exceed—milligrammes per normal cubic metre
200 tonnes per day	(All Sections)	400
Greater than 200 tonnes per day	Total dust (All Section)	250

The Central and State Pollution Control Boards may fix stringent standards, not exceeding 250 milligrammes per normal cubic metre for smaller plants and 150 milligrammes per normal cubic metre for larger plants if the industry is located in an area which, in their opinion, requires more stringent standards.

Where continuous monitoring integrators are provided on dust emission lines, the integrated average values over a period, to be fixed by the Central and State Boards but not exceeding 72 hours

shall be considered instead of momentary dust emission values for conformity to standards."

[No. 1 (18)/86-PL]

Principal Rules published vide S.O. No. 844(E) dated 19-11-86.

Amending Rules published vide S.O. No. 82(E), 83(E) and 84(E) dated 16-2-87.

S.O. 394(E).—In exercise of the powers conferred under clause (*a*) of section 19 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby authorise the officers and authorities listed in column (2) of the Table hereto for the purposes of the said section with the jurisdiction mentioned against each of them in column (3) of that Table :

TABLE

Serial No.	*Officer*	*Jurisdiction*
1	2	3
1.	Any Director, Joint Secretary, Adviser or Additional Secretary to the Government of India in the Department of Environment, Forests and Wildlife.	Whole of India
2.	The Chairman or Member-Secretary of the Central Board for the Prevention and Control of Water Pollution constituted under section 3 of the water (Prevention and Control of Pollution) Act, 1974 (6 of 1974).	Whole of India
3.	The Government of the State (represented by the Secretary (to the State Government incharge of environment.	Whole of the State

1	2	3
4.	The Chairman or Member-Secretary of the State Board for the Prevention and Control of Water Pollution constituted under section 4 of the Water (Prevention and Control of Pollution) Act, 1974 (6 of 1974) or a State Board for the Prevention and Control of Air Pollution constituted under section 5 of the Air (Prevention and Control of Pollution) Act, 1981 (14 of 1981).	Whole of the State
5.	Collector	Whole of Revenue District
6.	Regional Officers of the Central Board for the Prevention and Control of Water Pollution who have been delegated powers under sections 20, 21, 23 of the Water (Prevention and Control of Pollution) Act, 1974 (6 of 1974) and section 24 of the Air (Prevention and Control of Pollution) Act, 1981 (14 of 1981).	Area as laid down by the Central Board
7.	Regional Officers of the State Board for the prevention and control of water pollution who have been delegated powers under sections 20, 21 and 23 of the Water (Prevention and Control of Pollution) Act, 1974.	Area as laid down by the State Board
8.	Regional Officers of the State Board for the Prevention and Control of Air Pollution who have been delegated powers under section 24 of the	Area has laid down by the State Board

1	2	3	4
	Air (Prevention and Control of Pollution) Act, 1981.		

[No. 1(2)/87-PL]
T.N. SESHAN, Secy.

MINISTRY OF ENVIRONMENT AND FORESTS

(Department of Environment, Forests and Wildlife)
New Delhi, the 26 March, 1987

CORRIGENDUM

S.O. 238 (E).—In the notification of the Government of India in the Ministry of Environment and Forests, Department of Environment, Forests and Wildlife No. S.O. 83(E) dated the 16th February, 1987 for "sub-section (1) of Section 10", read "sub section (1) of section 10 of the Environment (Protection) Act, 1986 (29 of 1986)".

[No. 1(18)/86-PL]

CORRIGENDUM

S.O. 239 (E).—In the notification of the Government of India in the Ministry of Environment and Forests, Department of Environment, Forests and Wildlife No. S.O. 84(E) dated the 16 February, 1987 for "sub-section (1) of Section 11", read "sub-section (1) of section 11 of the Environment (Protection) Act, 1986 (29 of 1986)".

[No. 1 (18)/86-PL]
T.N. SESHAN, Secy.

MINISTRY OF ENVIRONMENT AND FORESTS

(Department of Environment, Forests & Wildlife)
New Delhi, the 18th April, 1987

NOTIFICATION

S.O. 443 (E) :—In exercise of the powers conferred by section 25 of the Environment (Protection) Act, 1986 (29 of 1986), the

Central Government hereby makes the following rules, further to amend the Environment (Protection) Rules, 1986, namely :—

1. (1) These rules may be called the Environment (Protection) Third Amendment Rules, 1987.

   (2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Schedule to the Environment (Protection) Rules, 1986, after serial number 10 and the entries relating thereto the following serial number and entries shall be inserted, namely :—

1	2	3	4
"11.	Stone crushing unit.	Suspended particulate matter.	The suspended particulate matter measured between 3 metres and 10 metres from any process equipment of a stone crushing unit shall not exceed 600 microgrammes per cubic metre."

[No. 1 (18) 86-PL]

T.N. SESHAN, Secy.

Principal rules published vide S.O. No. 844 (E) dated 19-11-1976.

Amending rules published vide S.O. No. 82 (E), 83 (E) and 84 (E) dated 16-2-1987 and Second Amendment Rules notified under S.O. 393 (E) dated 16-4-1987.

MINISTRY OF ENVIRONMENT AND FORESTS

(Department of Environment, Forests and Wildlife)

New Delhi, the 21st July, 1987

NOTIFICATION

S.O. 728(E).—In exercise of the powers conferred by clause (*b*) of sub-section (1) of section 12 and section 13 of the Environment

(Protection) Act, 1986 (29 of 1986), the Central Government hereby recognises, (*a*) the laboratories specified in column (2) of the Table below as environmental laboratories to carry out the functions entrusted to the environmental laboratories under the said Act and the rules made thereunder, and (*b*) specifies the persons in column (3) of the Table to be the Government Analysis for the purposes of analysis of samples of air, water, soil or other substances sent for analysis by the Central Government or the officer empowered under section 11 of the Act.

TABLE

Serial Number (1)	*Number of the Laboratories* (2)	*Number of the Analysit* (3)
1.	Vimta Labs, 2-2-18/46 Durgabai Deshmukh Colony. Bagh Amberpet, Hyderabad-500 013.	1. Dr. S.P. Vasireddi, Director 2. Mr. U. Appa Rao Assistant Director. 3. Mr. G. Venu Gapala Krishna, Chemist.
2.	Regional Laboratory of Gujarat Pollution Control Board, Race Course Road, ERI Circle, Baroda-390 007.	1. Dr. B.G. Soni, Scientific Officer. 2. Mr. G.K. Trivedi, Scientific Officer. 3. Mr. M.V. Soni, Senior Scientific Assistant. 4. Mr. J.B. Brahmbhatt, Senior Scientific Assistant. 5. Smt. Dipti S. Salat, Senior Scientific Assistant. 6. Mr. R.B. Upadhayay, Junior Scientific Assistant.

1	2	3
3.	Public Health Engineering Laboratory, Baroda Municipal Corporation, Khanderao, Market, Place Road, Baroda-1.	1. Mr. Prabhakar Omkar Chaudhari, Chemist. 2. Mr. G.J. Savani, Assistant Chemist. 3. Mr. Vinubhai D. Patel, Assistant Chemist.
4.	Himachal Pradesh State Board for the Prevention and Control of Water Pollution Laboratory, HIG-67, Sector IV, Parwanoo-173 220, Himachal Pradesh.	1. Mr. Pawan Jit Singh Dadhwal, Assistant Environmental Engineer.
5.	Essen and Company Laboratory, No. 550, Eighth Main Road, Malleswaram West, Banglore-560 055.	1. Dr. J. Rajaram, Director. 2. Mr. K.S. Sundarakrishnan, Chemist. 3. Mr. S. Charles Marsland, Chemist.
6.	Research and Development Centre Laboratory, The Fertilisers and Chemicals Travancore Limited (FACT Ltd.) Udyogamandal, Via-Cochin-633 501.	1. Dr. A.P. Rao, Deputy General Manager (R & D). 2. Mr. K.C. Geeverghese, (R & D) Officer. 3. Mr. K.R.R. Nair, (R & D) Officer. 4. Mr. K.V. Jose, Research Officer. 5. Mrs. P.L. Elsie, Research Officer. 6. Mr. A. Ayyappaswamy, Junior Research Officer.

1	2	3
		7. Mr. G. Gopakumar, Junior Research Officer.
		8. Mr. B. Salim, Research Chemist.
		9. Mr. K.S. Ramachandran, Research Chemist.
7.	Central Laboratory, Kerala State Pollution Control Board, S.R.M. Road, Cochin-682 018.	1. Dr. R. Balachandran, Environmental Scientist.
		2. Mr. B. Raveendran Pillai, Assistant Environmental Scientist.
		3. Ms. M. Sudha Devi, Assistant Scientist.
		4. Mr. V. Ramachandran, Assistant Scientist.
		5. Mr. V.K. Rajeevan, Assistant Scientist.
		6. Mr. M.P. Chandrasekharan Assistant Scientist.
		7. Ms. B. Saraswatuy Amma, Assistant Environmental Scientist.
		8. Mr. K.S. Vijayakumar, Assistant Environmental Scientist.
		9. Ms. P.K. Geethakumary, Assistant Environmental Scientist.
8.	Cochin Refineries Pollution Control Laboratory, Chochin Refineries	1. Mr. A. Rebello, Senior Manager (Quality Control).

1	2	3
	Limited, Post Bag 2, Ambalamugal-682 302 (Kerala).	2. Mr. K.V. Satya Das, Manager (Quality Control). 3. Mr. C.I. Roy, Manager (Quality Control). 4. Mr. C.N. Bhaskara, Manager. 5. Mr. K.P. Subramanian, Senior Quality Control Officer. 6. Mr. V.H. Muhammed, Senior Quality Control Officer. 7. Mr. K.P. Yacob, Junior Officer (Quality Control). 8. Mr. T.P. Antony, Quality Control Officer. 9. Mr. V. Paily, Quality Control Officer. 10. Mr. M.L. Rajan Potty, Junior Quality Control Officer.
9.	Environmental Engineering Laboratory, Walchand College of Engineering, Wishrambag, Sangli-416 415 (Maharashtra)	1. Dr. Bollapragada Subha Rao, Professor & Head of Civil Engineering Department. 2. Dr. Suresh Vishnu Ranade, Assistant Professor. 3. Prof. Jayant Mahadeo Gadgil, Lecturer. 4. Mr. Ganesh Gopal Watve, Senior Laboratory Assistant.

1	2	3
10.	Environmental Engineering Research Division Laboratory, Maharashtra Engineering Research Institute, Dindori Road, Nashik-422 004.	1. Mr. R.A. Altekar, Research Officer. 2. Mr. S.G. Kokani, Scientific Officer. 3. Mr. S.S. Jadhav, Senior Scientific Assistant. Mr. A.G. Deshmukh, Senior Scientific Assistant. 5. Mr. R.D. Mahajan, Junior Scientific Assistant. Mr. S.D. Pagar, Junior Scientific Assistant. Mr. S.T. Kulkarni, Research Assistant. Mr. C.M. Tribhuwan, Research Assistant. Sau. C.A. Varade, Research Assistant.
11.	Soil Science & Agricultural Chemistry, Laboratory, Department of Agricultural Chemistry, P.K.V. Akola-444 001.	1. Dr. V.N. Deshmukh.
12.	Laboratory of Environmental Engineering Section, Civil Engineering Department. University of Roorkee, Roorkee.	1. Dr. R.P. Mathur, Professor. 2. Mr. C.L. Toshniwal, Professor. 3. Dr. Arvind Kumar, Reader.

1	2	3
		4. Dr. Indu Mehrotra, Reader.
		5. Mr. Pradeep Kumar, Lecturer.
		6. Mr. U.B. Chitranshi, Lecturer.
13.	Trace Metal Environmental Laboratory,	1. Dr. R. Nath, Professor and Head.
	Department of Bio-Chemistry.	2. Dr. Vipin Kumar Paliwal, Research Associate.
	Post Graduate Institute of Medical Education Research Chandigarh-160012.	3. Dr. (Mrs) Kiran Dip-Gill, Lecturer.
14.	Environmental Laboratory, Modern	1. Dr. V.D. Patil, Principal.
	College, Vashi, New Bombay Pin. 400 705	2. Prof. H.V. Jadhav, Head, Chemistry Department.
		3. Prof. P.B. Patil Lecturer.
		4. Prof. (Mrs.) Jyoti. Arundhati Nand Kishore, Head, Microbiology Department.
		5. Prof. H.U. Mulla, Lecturer.
		6. Prof. N.B. Kadampatil, Lecturer.
		7. Prof. Gune Prabhakar Rathakar, Lecturer.

1	2	3
		8. Prof. Jogdand Shreepad Neelkhanth, Lecturer.
		9. Miss J.Y. Mulla, Lecturer.
15.	Central Laboratory Maharashtra Pollution Control Board, Army & Navy Building, Ground Floor, 148, M.G. Road, Fort, Bombay-400 023.	1. Dr. K.B. Deshpande, Senior Scientific Officer. 2. Mr. K.L. Mali, Junior Scientific Officer,
16.	Gujarat Fisheries Aquatic Science Research Institute, Okha. Pin : 361350.	1. Prof. Niranjan D. Chhaya, Deputy Commissioner or Fisheries. 2. Mr. M. Bhaskaran, Research Officer. 3. Mr. Y.B. Raval, Assistant Research officer. 4. Mr. K.N. Prasad, Senior Research Assistant. 5. Mr. D.J. Vadher, Senior Research Assistant. 6. Mr. V.R. Khadse, Senior Research Assistant. 7. Mr. D.V. Nandasana, Senior Research Assistant.
17.	Central Food Laboratory 3, Kyd Street, Calcutta-700 016.	1. Dr. S. Vanchinathan, Microbiologist. 2. Smt. Gyatri Biswas, Senior Analyst. 3. Mr. Asit Ranjan Sen, Technical officer.

1	2	3
		4. Mr. Kali Prasad Banerjee, Junior Analyst.
		5. Mr. Jyoti Kumar Sarkar, Junior Analyst.
		6. Mr. Shyamal Kante Haldar, Junior Analyst.
		7. Dr. Ajit Kumar Roy, Senior Technical Assistant.
		8. Mr. Hem Nath Das, Senior Technical Assistant.
		9. Km. Namita Ghosh, Senior Technical Assistant.
		10. Dr. Jagatbandhu Chakraborty, Technical Assistant.
		11. Mr. Kiran Shankar Biswas, Technical Assistant.
		12. Mr. Maya Mitra, Technical Assistant.
		13. Mr. Utpal Chandra Sarkar, Technical Assistant.
		14. Mr. Swapan Kumar Bhattacharyya, Senior Laboratory Assistant.
		15. Mr. Rajat Roy, Senior Laboratory Assistant.
		16. Mr. Sankar Prasad Chandra. Laboratory Assistant.
		17. Mr. Paritosh Naskar, Laboratory Assistant.
		18. Mr. Chitaranjan Haldar, Laboratory Assistant.

1	2	3
		19. Mr. Subrata Kumar Sankar Laboratory Assistant.
		20. Mr. Sibir Kumar Basu Roy Chaudhury, Field Assistant.

[No. 1 (32)86—PL]
T.N. SESHAN, Secy.

MINISTRY OF ENVIRONMENT AND FORESTS
(Department of Environment, Forests and Wildlife)
New Delhi, the 23rd September, 1987

NOTIFICATION

S.O. 838 (E)—In exercise of the powers conferred by Clause (*b*) of sub-section (1) of section 12 and section 13 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby recognises, (*a*) the laboratories specified in column (2) of the Table below as environmental laboratories to carry out the functions entrusted to the environmental laboratories under the said Act and the rules made thereunder, and (*b*) specifies the persons in column (3) of the Table to be the Government Analysts for the purposes of analysis of samples of air, water, soil or other substances sent for analysis by the Central Government or the officer empowered under section 11 of the Act and amend the notification of the Government of India in the Ministry of Environment and Forests No. SO 728 (E) dated the 21st July, 1987 as provided in paragraph 2.

TABLE

1	2	3
1.	State Forests Research Institute, Madhya Pradesh Forest Department, Polipather, Jabalpur-482008.	1. Dr. Gulam Mohammed, Technical Assistant. 2. Mr. Parvej Jalil, Research Associate. 3. Mr. H.D. Kulkarni, Forest Genetiest.

1	2	3
2.	Department of Microbiology, University of Poona, Ganesh Khind, Pune-411007	1. Dr. Vinay B. Rale, Analyst. 2. Dr. M.V. Panse, Analyst. 3. Dr. B.P. Kapadnis, Analyst. 4. Dr. V.A. Chopade, Analyst. 5. Miss M.R. Chinchore, Analyst.
3.	Pollution Control Research Institute, BHEL, Ranipur, Hardwar-249403	1. Prof. S.P. Mahajan, Head. 2. Mr. Paraveen Kumar Singh, Engineer. 3. Mr. Anil Jain, Engineer. 4. Mr. Rajiv Maheshwari Engineer. 5. Mr. G. Sambiah, Senior, Engineer. 6. Mr. Avinish Kumar, Engineer. 7. Dr. N.G. Shrivastava, Junior Engineer. 8. Mr. A.K. Gupta, Manager. 9. Dr. (Mrs.) Neelam Srivastava, Junior Engineer.
4.	Centre for Bio-Chemicals, CSIR, V.P. Chest Institute Buildings, University Campus, Delhi-110007.	1. Dr. N.P. Tulsani, Scientist. 2. Mr. S.K. Aggarwal, Technical Officer.
5.	Control, Research & Development Laboratory, Uranium Corporation of India Ltd. Jaduguda lines, Singhbhum, Bihar-832102.	1. Mr. R.U. Choudhary, Assistant Superientendent. 2. Dr. Ramesh Chandra, Assistant Superintendent. 3. Mr. Joydeb Ray Scientific Assistant. 4. Mr. A.K. Sarkar, Scientific Assistant.

1	2	3
		5. Mr. D.P. Saha, Scientific Assistant.
		6. Mr. A.P. Banerjee, Scientific Assistant.
		7. Mr. Asit Baran Chakravorthy, Scientific Assistant.
		8. Mr. S. Venkat Raman, Scientific Assistant.
		9. Mr. Rajeshwar Prasad Singh, Scientific Assistant.
		10. Mr. Mohammed Nadir Ali, Scientific Assistant.
		11. Mr. N. Maity, Scientific Assistant.
		12. Mr. R.M. Karan, Scientific Assistant.
		13. Mr. Aish Mohammed Ansari, Scientific Assistant.
		14. Mr. Jagdish Sahay, Laboratory Assistant.
6.	Division of Soil Science & Plant of Nutrition, Division of Microbiology,	1. Dr. C.C. Biddappa, Head, (Social Sciences).
	Central Plantation Corporation Research Institute, (ICAR), Kasargod-671742.	2. Dr. George V. Thomas, Scientist.
7.	Chemistry Laboratory, Irrigation and Power Research Institute, Amritsar-143001, Punjab.	1. Dr. Mahendra Kumar, Research Officer.

1	2	3
8.	Central Laboratory, M.P. Pradushan Nivaran Mandal, Paryavaran Parisar, E-5, Sector, Ravi Shankar Nagar, Bhopal, (MP).	1. Dr. M.M. Singh, Chief Chemist. 2. Mr. Surendra Doriwal, Chemist. 3. Mr. Neeraj K. Verma, Chemist. 4. Mr. R.S. Bhawasar, Junior Scientist.
9.	Research & Development Laboratory, Project & Development India Ltd., Sindri, Dhanbad District.	1. Dr. R.M. Bhatnagar, Additional Superintendent. 2. Dr. V.S. Gupta, Additional Superintendent. 3. Mr. Y.K. Verma, Additional Superintendent. 4. Dr. A.D. Pandey, Additional Superintendent. 5. Mr. D.K. Sen, Additional Superintendent. 6. Mr. G.R. Bhatnagar, Deputy Superintendent. 7. Mr. K.K. Mallick, Deputy Superintendent. 8. Mr. C.D. Banerjee, Deputy Superintendent. 9. Dr. A.T. Balagopal, Deputy Superintendent. 10. Mr. M.K. Sen, Deputy Superintendent. 11. Dr. A. Chattopadhyay, Deputy Superintendent. 12. Mr. N. Raman, Assistant Superintendent.

1	2	3
		13. Dr. V.K. Jindal, Assistant Superintendent.
10.	Department of Biosciences Laboratory, South Gujarat University, Surat-395007. (Gujarat)	1. Prof. B.S. Vaidya, Head. 2. Prof. P.K. Hira Dhar, Professor of Zoology. 3. Dr. Nagar A. Pankaj, Microbiologist. 4. Dr. P.V. Desai, Microbiologist. 5. Dr. Kewal Krishan, Lecturer. 6. Dr. Tank K. Shantilal, Senior Research Fellow. 7. Dr. M. Narasimha Reddy, Technician.
11.	Central Laboratory, Tamil Nadu Pollution Control Board, 25, Radhakrishnan Road, Madras-600004.	1. Dr. K. Narayanan, Chief Scientific Officer. 2. Dr. V.N. Rayudu, Deputy Chief Scientific Officer.
12.	National Institute of Occupational Health Laboratory, P.O. Civil Hospital, Meghani Nagar, Ahmedabad-380016.	1. Dr. P.J. Parikh, Assistant Director. 2. Dr. S.K. Ghosh, Senior Research Officer. 3. Dr. C.B. Pandiya, Research Officer. 4. Mr. M.P. Shah, Research Officer. 5. Dr. T.S. Patel, Research Officer. 6. Dr. S.G. Ruparelia, Research Officer. 7. Dr. N.B. Ghodasara, Research Officer.

1	2	3
		8. Dr. Jitesh P. Jani, Research Officer.
		9. Dr. (Miss) V.N. Gokani, Research Officer.
		10. Mr. C.V. Raiyani, Research Officer.
13.	Environmental Engineering Laboratory, Sri Venkateswara University College of Engineering, Tirupati-Pin : 517502.	1. Professor P. Pratapa Mouli, Head. 2. Dr. N. Venkata Subbaya, Lecturer.
14.	Orissa State Prevention and Control of Pollution Board Laboratory, No. A-118, Nilakantha Nagar, Unit, III Bhubaneshwar-751012.	1. Mr. D.R. Behera, Scientist. 2. Mr. P.K. Prusty, Scientist. 3. Mr. Bibeka Nanda Bhol, Scientist. 4. Mr. D.K. Rout, Scientist.

2. In the said notification, in the Table, after serial number 17 and the entries relating thereto, the serial number 1 to 14 and the entries relating thereto of the Table appearing in paragraph 1 shall be inserted as serial number 18 to 31 and the entries relating thereto respectively.

[No. 1 (32) 86-PL]

T.N. SESHAN, Secy.

MINISTRY OF ENVIRONMENT & FORESTS

(Department of Environment, Forests & Wildlife)

New Delhi, the 10th February, 1988

NOTIFICATION

S.O. 152(E).—In exercise of the powers conferred by section 23 of the Environment (Protection) Act, 1986 the Central Government

hereby delegates the powers vested in it under section 5 of the Act to the State Governments of Andhra Pradesh, Assam, Bihar, Gujarat Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Mizoram, Orissa, Rajasthan, Sikkim and Tamil Nadu subject to the condition that the Central Government may revoke such delegation of powers in respect of all or any one or more of the State Governments or may itself invoke the provisions of section 5 of the Act, if in the opinion of the Central Government such a course of action is necessary in public interest.

[No. 1(38)/86-PL]
T.N. SESHAN, Secy.

MINISTRY OF ENVIRONMENT AND FORESTS

(Department of Environment, Forests and Wildlife)

New Delhi, the 18th January, 1988

NOTIFICATIONS

S.O. 62(E).—In exercise of the powers conferred by sub-section (1) of section 11 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby empowers the persons listed in the Table here-below for the purposes or that sub-section and amends the notification of the Government of India in the Ministry of Environment and Forests, Department of Environment, Forests and Wildlife No. SO. 94(E) dated the 16th February, 1987.

2. In the Table appearing in the said notification, after serial number 59 and the entries relating thereto, the following serial number and entries shall be added, namely :—

1	2	3
'60.	Chief Inspector of Mines Safety	The Mines Act, 1952 and the rules and regulations made thereunder."

Foot Note : Principal Notification published vide S.O. No. 84(E), dated 16th February, 1987.

[No. 1(18)/86-PL]

S.O. 63(E) :—In exercise of the powers conferred by sub-section (1) of section 10 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby empowers the persons listed in the Table here-below for the purposes of that sub-section and amends the notification of the Government of India in the Ministry of Environment and Forests, Department of Environment, Forests and Wildlife No. S O. 83 (E), dated the 16th February, 1987.

⌝. In the Table appearing in the said notification, after serial number 59 and the entries relating thereto, the following serial number and entries shall be added, namely—

1	2	3
"60.	Chief Inspector of Mines Safety	The Mines Act, 1952 and the rules and regulations made thereunder."

Foot Note : Principal Notification published vide S.O. No. 84(E) dated 16th February, 1987.

[No. 1(18)/86-PL]

S.O. 64 (E) :—In exercise of the powers conferred by section 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely :—

1. (1) These rules may be called the Environment (Protection) Fourth Amendment Rules, 1987.

   (2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986 (herein-after referred to as the principal rules), sub-rule (3) of rule 4 shall be renumbered as sub-rule (3*a*) of that rule and after sub rule (3*a*) as so renumbered, the following sub-rule shall be inserted, namely :—

"(3*b*) Where the proposed direction is for the stoppage or regulation of electricity or water or any other service affecting the

carrying on any industry, operation or process and is sought to be issued to an officer or an authority, a copy of the proposed direction shall also be endorsed to the occupied of the industry, operation or process, as the case may be, and objections, if any, filed by the occupier with an officer designated in this behalf shall be dealt with in accordance with the procedures under sub-rules (3*a*) and (4) of this rule.

Provided that no opportunity of being heard shall be given to the occupier if he had already been heard earlier and the proposed direction referred to in sub-rule (3*b*) above for the stoppage or regulation of electricity or water or any other service was the resultant decision of the Central Government after such earlier hearing."

3. In the principle rules, for rule 6, the following rule shall be substituted, namely :—

"6. Procedure for taking samples :

The Central Government or the officer empowered to take samples under section 11 shall collect the sample in sufficient quantity to be divided into two uniform parts and effectively seal and suitably mark the same and permit the person from whom the sample is taken to add his own seal or mark to all or any of the portions so sealed and marked. In case where the sample is made up in containers or small volumes and is likely to deteriorate or be otherwise damaged if exposed, the Central Government or the officer empowered shall take two of the said samples without opening the containers and suitably seal and mark the same. The Central Government or the officer empowered shall dispose of the samples so collected as follows :—

(*i*) One portion shall be handed over to the person from whom the sample is taken under acknowledgement ; and

(*ii*) the other portion shall be sent forthwith to the environmental laboratory or analysis."

4. In the schedule I to the principal Rules, after serial number 11 and the entries relating thereto, the following serial numbers and entries shall be inserted, namely :—

1	2	3	4
"12.	Coke ovens		Concentrations in the effluents when discharged into inland surface waters not to exceed milligramme per litre (except for pH)
		pH	5.5—9.0
		Biochemical Oxygen Demand (20°C for 5 days)	30
		Suspended Solids	100
		Phenolic Compounds (As C_6H_5OH)	5
		Cyanides (as CN)	0.2
		Oil & Grease	10
		Ammonical Nitrogen (as N)	50
13.	Synthetic Rubber		Concentration in the effluents when discharged into inland surface waters not to exceed milligramme per litre (except for colour, and pH)
		Colour	Absent
		pH	5.5—9.0

1	2	3	4
		Biochemical Oxygen Demand (20°C for 5 days)	50
		Chemical Oxygen Demand	250
		Oil & Grease	10.0
14.	Small Pulp and Paper Industry		Concentration no to exceed milli-gramme per litre (except for pH and sodium absorption ratio)
	*Discharge into inland surface water	pH	5.5—9.0
		Suspended Solids	100
		BOD	30
	Disposal on land	pH	5.5—9.0
		Suspended Solids	100
		BOD	100
		Sodium Absorption Ratio	26
15.	Fermen-tation Industry (Distilleries, Maltries and Breweries)		Concentration in the effluents not to exceed milli-gramme per litre (except for pH and colour & Odour)
		pH	5.5—9.0
		Colour & Odour	Absent
		Suspended Solids	100
		BOD (5 days at 20°C)	
		—disposal into inland surface waters	30
		—disposal on land	100

*Waste water generation shall not exceed 250 metres cube per tonne of paper produced.

1	2	3	4			
16.	Leather Tanneries		Concentration in the effluents not to exceed milligramme per litre (except for pH and percent sodium)			
			Inland Surface Waters	Public Sewers	Land for Irrigation	Marine Coastal areas
			(a)	(b)	(c)	(d)
		Suspended Solids	100	100	200	100
		BOD-5 days at 20°C	30	350	100	100
		pH	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0
		Chlorides (as Cl)	1000	1000	600	
		Hexavalent Chromium (Cr^{6+})	0.1	0.2	0.1	1.0
		Total Chromium (as Cr)	2.0	2.0	2.0	2.0
		Sulphides (as S)	2.0	5.0	—	5.0
		Sodium, per cent	—	60	60	—
		Boron (as B)	2.0	2.0	2.0	—
		Oil & Grease	10	20	10	20
17.	Fertilizer Industry		Concentration in the effluents not to exceed milligramme per litre (except for pH)			

1	2	3	4	
	Effluents—Straight Nitrogenous Fertilizers, excluding the Calcium Ammonium Nitrate and Ammonium Nitrate and Ammonium Nitrate Fertilizer		Plants Commissioned January 1, 1982, onwards (a)	Plants Commissioned prior to January 1, 1982 (b)
		pH	6.5—8.0	6.5—8.0
		Ammonical Nitrogen	50	75
		Total Kjeldahl Nitrogen	100	150
		Free Ammonical Nitrogen	4	4
		Nitrate Nitrogen	10	10
		Cyanide as CN	0.2	0.2
		Vanadium as V	0.2	0.2
		Arsenic as As	0.2	0.2
		Suspended Solids	100	100
		Oil and Grease	10	10

	*Hexavalent Chromium as Cr	0.1	0.1
	*Total Chromium as Cr	2.0	2.0
Straight Nitrogenous Fertilizers including Calcium Ammonium Nitrate and Ammonium Nitrate Fertilisers		Plants commissioned January 1, 1982, onwards *(a)*	Plants commissioned prior to January 1, 1982 *(b)*
	pH	6.5—8.0	6.5—8.0
	Ammonical Nitrogen	50	75
	Total Kjeldahl Nitrogen	100	150
	Free Ammonical Nitrogen	4	4
	Nitrate Nitrogen	20	20
	Cyanide as CN	0.2	0.2
	Vanadium as V	0.2	0.2
	Arsenic as As	0.2	0.2
	Suspended Solids	100	100

*To be complied with at the outlet of Chromate removal unit.

	Oil & Grease	10	10
	*Hexavalent Chromium as Cr	0.1	0.1
	*Total Chromium as Cr	2.0	2.0
Complex fertilizers excluding Calcium Ammonium Nitrate, Ammonium Nitrate & Ammonium Nitrophosphate Fertilisers		Plants commissioned January 1, 1982 onwards (*a*)	Plants commissioned prior to January 1, 1982 (*b*)
	pH	6.5—8.0	6.5—8.0
	Ammonical Nitrogen	50	75
	Free Ammonical Nitrogen	4	4
	Total Kjeldahl Nitrogen	100	150
	Nitrate Nitrogen	10	10
	Cyanide as CN	0.2	0.2
	Vanadium as V	0.2	0.2
	Arsenic as As	0.2	0.2

*To be complied with at the outlet of chromate removal unit.

Phosphate as P	5	5
Oil and Grease	10	10
Suspended Solids	100	100
*Fluoride as F	10	10
**Hexavalent Chromium as Cr	0.1	0.1
**Total Chromium as Cr.	2.0	2.0

*To be complied with at the outlet of fluoride removal unit. If the recipient system so demands, fluoride as F shall be limited to 1.5 mg/1.

**To be complied with at the outlet of chromate removal unit.

Complex fertilizers including Calcium Ammonium Nitrate, Ammonium Nitrate & ammonium nitrophosphate Fertilizers		Plants commissioned January 1, 1982 onwards	Plants commissioned prior to January 1, 1982
		(*a*)	(*b*)
	pH	6.5—8.0	6.5—8.0
	Ammoniacal Nitrogen	50	75
	Free Ammonical Nitrogen	100	100

Nitrate Nitrogen	20	20
Cyanide as CN	0.2	0.2
Vanadium as V	0.2	0.2
Arsenic as As	0.2	0.2
Phosphate as P	5	5
Oil & Grease	10	10
Suspended Solids	100	100
*Fluoride as F	10	10
**Hexavalent Chromium as Cr.	0.1	0.1
**Total Chromium as Cr.	2.0	2.0

*To be complied with at the outlet of fluoride removal unit. If the recipient system so demands, fluoride as F shall be limited to 1.5 mg/1.

**To be complied with at the outlet of chromate removal unit.

Straight Phosphatic Fertilizers

pH	7.0—9.0
Phosphate as P	5
Oil and Grease	10
Suspended Solids	100
*Fluoride as F	10
**Hexavalent Chromium as Cr	0.1
**Total Chromium as Cr.	2.0

Emissions —Phosphatic Fertilizers Fertilizers and particulate matter emission)	Phosphoric acid manufacturing unit Granulation, mixing and grinding of rockphosphate	25 milligramme per normal cubic metre as total Fluoride 150 milligramme per normal cubic metre of particulate matter
—Urea (Particulate matter emission)	Prilling Tower	
	Commissioned prior to 1-1-1982	150 milligramme per normal cubic metre or 2 kilogramme per tonne of product.
	Commissioned after 1-1-1982	50 milligramme per normal cubic metre or 0.5 kilogramme per tonne of product.

*To be complied with at the outlet of fluoride removal unit. If the receipient system so demands, fluorides as F shall be limited to 1.5 mg/l.

**To be complied with at the outlet of chromate removal unit.

18. Aluminium	Particulate Matter Emissions	
	—Calcination	250 milligramme per normal cubic metre of particulate

		—Smelting	150 milligramme per normal cubic metre of particulate matter
19.	Calcium Carbide	Particulate Matter Emission	
		—Kiln	250 milligramme per normal cubic metre
		—Arc Furnance	150 milligramme per normal cubic metre
20.	Carbon Black	Particulate Matter Emission	150 milligramme per normal cubic metre
21.	Copper, Lead and Zinc Smelting	Particulate Matter Emission in concentrator	150 milligramme per normal cubic metre
		Emission of Oxides of sulphur in Smelter & Convertor	Off-gases must be utilised for sulphuric acid manufacture. The limits of sulphur dioxide emission from stock shall not exceed 4 kilogramme per tonne of concentrated (One hundred per cent) acid produced.

22.	Nitric Acid (emission of oxides of nitrogen	Emission of Oxides of Nitrogen	3 kilogramme of oxides of nitrogen per tonne of weak acid (before concentration) produced.
23.	Sulphuric Acid (emission of sulphur dioxide and acid mist)	Sulphur dioxide Emissions	4 kilogramme per tonne of concentrated (one hundred per cent) acid produced.
		Acid mist	50 milligramme per normal cubic metre
24.	Iron & Steel (Integrated)	Particulate matter Emission	
		—Sintering Plant	150 milligramme per normal cubic metre
		—Steel making	
		– during normal operations	150 milligramme per normal cubic metre
		—during oxygen lancing	400 milligramme per normal cubic metre
		—Rolling Mill	150 milligramme per normal cubic metre
		Carbon monoxide from coke even	3 kilogramme per tonne of coke produced."

5. In the Schedule II to the principal rules, under column (3), against serial number 2, for the entries (*i*) and (*ii*), the following entries shall be substituted, namely :—

"(*i*) Controller General of Mines

(*ii*) Regional Controller of Mines having local jurisdiction."

[No. 1(18)/86-PL]
T.N. SESHAN, Secy.

Principal Rules published vide S.O. No. 844 (E) dated the 19th November, 1986. Amending rules published vide S.O. No. 82 (E), 83 (E) and 84 (E) dated 16th February, 1987 :

Second Amendment rules notified under S.O. No. 399(E) dated 16th April, 1987 ; Third Amendment rules notified under S.O. No. 433 (E) dated 28th April, 1987.

THE WATER (PREVENTION AND CONTROL OF POLLUTATION) ACT, 1974

No. 6 of 1974

[23rd March 1974]

An Act to provide for the prevention and control of water pollution and the maintaining or restoring of wholesomeness of water, for the establishment, with a view to carrying out the purposes aforesaid, of Boards for the prevention and control of water pollution, for conferring on and assiging to such Boards powers and functions relating thereto and for matters connected therewith.

Whereas it is expedient to provide for the prevention and control of water pullution and the maintaining or restoring of wholesomeness of water, for the establishment, with a view to carrying out the purposes aforesaid, of Boards for the prevention and control of water pollution and for conferring on and assigning to such Boards powers and functions relating thereto ;

And whereas Parliament has no power to make laws for the States with respect to any of the matters aforesaid except as provided in articles 249 and 250 of the Constitution ;

And whereas in pursuance of clause (1) of article 252 of the Contitution resolutions have been passed by all the Houses of the Legislatures of the States of Assam, Bihar, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Rajasthan Tripura and West Bengal to the effect that the matters aforesaid should be regulated in those States by Parliament by law ;

Be it enacted by Parliament in the Twenty-fifth Year of the Republic of India as follows :

CHAPTER I

PRELIMINARY

Short Title, Application and Commencement

1. (1) This Act may be called the Water (Prevention and Control of Pollution) Act, 1974.

(2) It applies in the first instance to the whole of the States of Assam, Bihar Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Rajasthan, Tripura and West Bengal and the Union territories ; and it shall apply to such other State which adopts this Act by resolution passed in that behalf under clause (1) of article 252 of the Constitution.

(3) It shall come into force, at once in the States of Assam, Bihar, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Rajasthan, Tripura and West Bengal and in the Union teritories, and in any other State which adopts this Act under clause (1) of article 252 of the Constitution on the date of such adoption and any reference in this Act to the commencement of this Act shall, in relation to any State or Union territory, mean the date on which this Act comes into force in such State or Union territory.

Definitions

2. In this Act, unless the context otherwise requires,—

(*a*) "Board" means the Central Board or a State Board ;

(*b*) "Central Board" means the Central Board for the Prevention and Control of Water Pollution constituted under section 3 ;

(*c*) "Member" means a member of a Board and includes the chairman thereof ;

(*d*) "Occupier" in relation to any factory or premises means the person who has control over the affairs of the factory or the premises and where the said affairs are entrusted

to a managing agent, such agent shall be deemed to the occupier of the factory or the premises ;

(*e*) "Pollution" means such contamination of water or such alteration of the physical, chemical or biological properties of water or such discharge of any sewage or trade effluent or of any other liquid, gaseous or solid substance into water (whether directly or indirectly) as may, or is likely to, create a nuisance or render such water harmful or injurious to public health or safety, or to domestic, commercial, industrial, agricultural or other legitimate uses, or to the life and health of animals or plants or of acquatic organisms ;

(*f*) "Prescribed" means prescribed by rules made under this Act by the Central Government or, as the case may be, the State Government ;

(*g*) "Sewage effluent" means effluent from any sewerage system or sewage disposal works and includes sullage from open drains ;

(*h*) "State Board" means a State Board for the Prevention and Control of Water Pollution constituted under section 4 ;

(*i*) "State Government" in relation to a Union territory means the Administrator thereof appointed under article 239 of the Constitution ;

(*j*) "Stream" includes—

(*i*) river ;

(*ii*) water course (whether flowing or for the time being dry) ;

(*iii*) inland water (whether natural or artificial) ;

(*iv*) sub-terranean waters ;

(*v*) sea or tidal waters to such extent or, as the case may be, to such point as the State Government may, by

notification in the Official Gazette, specify in this behalf;

(*k*) "Trade effluent" includes any liquid, gaseous or solid substance which is discharged from any premises used for carrying on any trade or industry, other than domestic sewage.

CHAPTER II

THE CENTRAL AND STATE BOARDS FOR PREVENTION AND CONTROL OF WATER POLLUTION

Constitution of Central Board

3. (1) The Central Government shall, with effect from such date (being a date not later than six months of the commencement of this Act in the States of Assam, Bihar, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Rajasthan, Tripura and West Bengal and in the Union territories) as it may, by notification in the Official Gazette. appoint, constitute a Central Board to be called the Central Board for the Prevention and Control of Water Pollution to exercise the powers conferred on and perform the functions assigned to that Board under this Act.

(2) The Central Board shall consist of the following members, namely :—

(*a*) a full-time chairman, being a person having special knowledge or practical experience in respect of matters relating to the use and conservation of water resources or the prevention and control of water pollution or a person having knowledge and experience in administration institutions dealing with the matters aforesaid, to be nominated by the Central Government;

(*b*) five officials to be nominated by the Central Government to represent that Government;

(*c*) such number of persons, not exceeding five, to be nominated by the Central Government, from amongst the members of the State Boards, of whom not exceeding two shall be from those referred to in clause (*c*) of sub section (2) of section 4 ;

(*d*) three non-officials to be nominated by the Central Government, to represent the interests of agriculture, fishery or industry or trade or any other interest which in the opinion of the Central Government, ought to be represented ;

(*e*) two persons to represent the companies or corporations owned, controlled or managed by the Central Govern. ment, to be nominated by that Government ;

(*f*) a full-time member-secretary qualified in public health engineering and having administrative experience, to be appointed by the Central Government.

(3) The Central Board shall be a body corporate with the name aforesaid having perpetual succession and a common seal with power, subject to the provisons of this Act, to acquire, hold and dispose of property and to contract, and may, by the aforesaid name, sue or be sued.

Constitution of State Boards

4. (1) The State Government shall, with effect from such date (being a date not later than six months of the commencement of this Act in the State) as it may, by notification in the Official Gazette, appoint, constitute a State Board, under such name as may be specified in the notification, to exercise the powers conferred on and perform the functions assgined to that Board under this Act.

(2) A State Board shall consist of the following members, namely :—

(*a*) a full-time chairman, being a person having special knowledge or practical experience in respect of matters relating to the use and conservation of water resources or the prevention and control of water pollution or a person having knowledge and experience in administering institutions dealing with the matters aforesaid, to be nominated by the State Government ;

(*b*) five officials to be nominated by the State Government to represent that Government ;

(*c*) five persons to be nominated by the State Government from amongst the members of the local authorities functioning within the State ;

(*d*) three non-officials to be nominated by the State Government to represent the interests of agriculture, fishery or industry or trade or any other interest which, in the opinion of the State Government, ought to be represented ;

(*e*) two persons to reperesent the companies or corporations owned, controlled or managed by the State Government, to be nominated by that Government ;

(*f*) a full time member-secretary qualified in public health engineering and having administrative experience to be appointed by the State Government.

(3) Every State Board shall be a body corporate with the name specified by the State Government in the notification under sub-section (1), having perpetual succession and a common seal with power, subject to the provisions of this Act, to acquire, hold and dispose of property and to contract, and may, by the said name, sue or be sued.

(4) Notwithstanding anything contained in this section, no State Board shall be constituted for a Union territory and in relation to a Union territory, the Central Board shall exercise the powers and perform the functions of a State Board for the Union territory :

Provided that in relation to any Union territory the Central Board may delegate all or any of its powers and functions under this sub-section to such person or body of persons as the Central Government may specify.

Terms and Conditions of Service of Members

5. (1) Save as otherwise provided by or under this Act, a member of a Board, other than a member-secretary, shall hold office for a term of three years from the date of his nomination :

Provide that a member shall, notwithstanding the expiration of his term continue to hold office until his successor enters upon his office.

(2) The term of office of a member of a Board nominated under clause (*b*) of sub-section (2) of section 3 or clause (*b*) of sub-section (2) of section 4 shall come to an end as soon as he ceases to hold the office under the Central Government or, as the case may be, the State Government by virtue of which he was nominated.

(3) The Central Government or, as the case may be, the State Government may if it thinks fit, remove any member of a Board before the expiry of his term of office, after giving him a reasonable opportunity of showing cause against the same.

(4) A member of a Board, other than the member-secretary, may at any time resign his office by writing under his hand addressed—

(*a*) in the case of the chairman, to the Central Government or, as the case may be, the State Government ; and

(*b*) in any other case, to the chairman of the Board ;

and the seat of the chairman or such other member shall thereupon become vacant.

(5) A member of a Board, other than the member-secretary, shall be deemed to have vacated his seat if he is absent without reason, sufficient in the opinion of the Board, from three consecu-

tive meetings of the Board, or where he is nominated under clause (*c*) of sub-section (2) of section 3 or under clause (*c*) of sub-section (2) of section 4, if he ceases to be a member of the State Board, or as the case may be, of the local authority.

(6) A casual vacancy in a Board shall be filled by a fresh nomination of the person nominated to fill the vacancy shall hold office only for the remainder of the term for which the member in whose place he was nominated.

(7) A member of a Board shall not be eligible for renomination for more than two terms.

(8) The other terms and conditions of service of a member of a Board, other than the chairman and member-secretary, shall be such as may be prescribed.

(9) The other terms and conditions of service of the chairman shall be such as may be prescribed.

Disqualifications

6. (1) No person shall be a member of a Board, who—

(*a*) is, or at any time has been adjudged insolvent or has suspended payment of his debts or has compounded with his creditors, or

(*b*) is of unsound mind and stands so declared by a competent court, or

(*c*) is, or has been, convicted of an office which, in the opinion of the Central Government or, as the case may be, of the State Government, involves moral turpitude, or

(*d*) is, or at any time has been, convicted of an offence under this Act, or

(*e*) has directly or indirectly by himself or by any partner, any share or interest in any firm or company carrying on the business of manufacture, sale or hire of machi-

nery, plant, equipment, apparatus or fittings for the treatment of a sewage or trade effluents, or

(*f*) is a director or a secretary, manager or other salaried officer or employee of any company or firm having any contract with the Board, or with the Government constituting the Board, or with a local authority in the State, or with a company or corporation owned, controlled or managed by the Government for the carrying out of sewerage schemes or for the installation of plants for the treatment of sewage or trade effluents, or

(*g*) has so abused, in the opinion of the Central Government or as the case may be, of the State Government, his position as a member, as to render his continuance on the Board deterimental to the interest of the general public.

(2) No order of removal shall be made by the Central Government or the State Government, as the case may be, under this section unless the member concerned has been given a reasonable opportunity of showing cause against the same.

(3) Notwithstanding anything contained in sub-sections (1) and (7) of section 5, a member who has been removed under this section shall not be eligible for renomination as a member.

Vacation of Seats by Members

7. If a member of a Board becomes subject to any of the disqualifications specified in section 6, his seat shall becomes vacant.

Meetings of Board

8. A Board shall meet at least once in every three months and shall observe such rules or procedure in regard to the transaction of business at its meetings as may be prescribed.

Provided that if, in the opinion of the chairman, any business of an urgent nature is to be transcated, he may convene a meeting of the Board at such time as he thinks fit for the aforesaid purpose.

Constitution of Committees

9. (1) A Board may constitute as many committees consisting wholly of members or wholly of other persons or partly of members and partly of other persons, and for such purpose or purposes as it may think fit.

(2) A committee constituted under this section shall meet at such time and at such place, and shall observe such rules of procedure in regard to the transaction of business at its meetings, as may be prescribed.

(3) The members of a committee (other than the members of the Board) shall be paid such fees and allowances, for attending its meetings and for attending to any other work of the Board as may be prescribed.

Temporary Association of Persons with Board for Particular Purposes

10. (1) A Board may associate with itself in such manner, and for such purposes, as may be prescribed any person whose assistance or advice it may desire to obtain in performing any of its functions under this Act.

(2) A person associated with the Board under sub-section (1) for any purpose shall have a right to take part in the discussions of the Board relevant to the purpose, but shall not have a right to vote at a meeting of the Board, and shall not be a member for any other purpose.

Vacancy in Board not to Invalidate Acts or Proceedings

11. No act or proceeding of a Board or any committee thereof shall be called in question on the ground merely of the existence of any vacancy in or any defect in the constitution of, the Board or such committee, as the case may be.

Member-secretary and Offices and Other Employees of Board

12. (1) The terms and conditions of service of the member-secretary shall be such as may be prescribed.

(2) The member-secretary shall exercise such powers and perform such duties as may be prescribed or as may, from time to time, be delegated to him by the Board or its chairman.

(3) Subject to such rules as may be made by the Central Government or, as the case may be, the State Government in this behalf, a Board may appoint such officers and employees as it considers necessary for the efficient performance of its functions and the rules so made may provide for the salaries and allowances and other terms and conditions of of service of such officers and employees.

(4) Subject to such conditions as may be prescribed, a Board may from time to time appoint any qualified person to be a consulting engineer to the Board and pay him such salaries and allowances and subject him to such other terms and conditions of service as it thinks fit.

CHAPTER III

JOINT BOARDS

Constitution of Joint Boards

13. (1) Notwithstanding anything contained in this Act, an agreement may be entered into—

(*a*) by two or more Governments or contiguous States, or

(*b*) by the Central Government (in respect of one or more Union territories) and one or more Governments of States contiguous to such Union territory or Union territories,

to be in force for such period and to be subject to renewal for such further period, if any, as may be specified in the agreement to provide for the constitution of a Joint Board,—

(*i*) in a case referred to in clause (*a*), for all the participating States, and

(*ii*) in a case referred to in clause (*b*), for the participating Union territory or Union territories and he State or States.

(2) An agreement under this section may—

(*a*) provide, in a case referred to in clause (*a*) of sub-section (1) for the appointment between the participating States and in a case referred to in clause (*b*) of that sub-section, for the apportionment between the Central Government and the participating State Government or State Governments, of the expenditure in connection with the Joint Board ;

(*b*) determine, in a case referred to in clause (*a*) of sub-section (1), which of the participating State Governments and in a case referred to in clause (*b*) of that sub-section, whether the Central Government or the participating State Government (if there are more than one participating State, also which of the participating State Governments) shall exercise and perform the several powers and functions of the State Government under this Act and the references in this Act to the State Government shall be construed accordingly :

(*c*) provide for consultation, in a case referred to in clause (*a*) of sub-section (1), between the participating State Governments and in a case referred to in clause (*b*) of that sub-section, between the Central Government and the participating State Government or State Governments either generally or with reference to particular matters arising under this Act ;

(*d*) make such incidental and ancillary provisions, not inconsistent with this Act, as may be deemed necessary or expedient for giving effect to the agreeement.

(3) An agreement under this section shall be published, in a case referred to in clause (*a*) of sub-section (1), in the Official Gazette of the participating States and in a case referred to in clause (*b*) of that sub-section, in the Official Gazette of the participating

Union territory or Union territories and the participating State or States.

Composition of Joint Boards

14. (1) A Joint Board, constituted in pursuance of an agreement entered into under clause (*a*) of sub-section (1) of section 13 shall consist of the following members, namely :—

(*a*) a full-time chairman, being a person having special knowledge or practical experience in respect of matters relating to the use and conservation of water resources or the prevention and control of water pollution or a person having knowledge and experience in administering institutions dealing with the matters aforesaid, to be nominated by the Central Government ;

(*b*) two officials from each of the participating State to be nominated by the concerned participating State Government to represent that Government ;

(*c*) one person to be nominated by each of the participating State Governments from amongst the members of the local authorities functioning within the State concerned ;

(*d*) one non-official to be nominated by each of the participating State Governments to represent the interests of agriculture, fishery or industry or trade in the State concerned or any other interset which, in the opinion of the participating State Government, is to be represented ;

(*e*) two persons to be nominated by the Central Covernment to represent the companies or corporation owned, controlled or managed by the participating State Governments ;

(*f*) a full-time member-secretary qualified in public health engineering and having administrative experience, to be appointed by the Central Government.

(2) A Joint Board constituted in pursuance of an agreement entered into under clause (*b*) of sub-section (1) of section 13 shall consist of the following members, namely ;

(*a*) a full-time chairman, being a person having special knowledge or practical experience in respect of matters relating to the use and conservation of water resources or the prevention and control of water pollution or a person having knowledge and experience in administering institutions dealing with the matters aforesaid, to the nominated by the Central Government ;

(*b*) two officials to be nominated by the Central Government from the participating Union territory or each of the participating Union territories, as the case may be, and two officials to be nominated, from the participating State or each of the participating States, as the case may be, by the concerned participating State Government ;

(*c*) one person to be nominated by the Central Government from amongst the members of the local authorities functioning within the participating Union territory or each of the participating Union territories, as the case may be, and one person to be nominated, from amongst the members of the local authorities functioning within the participating State or each of the participating States, as the case may be, by the concerned participating State Government ;

(*d*) one non-official to be nominated by the Central Government and one person to be nominated by the participating State Government or State Governments to represent the interests of agriculture, fishery of industry or trade in the Union territory or in each of the Union terrotories or the State or in each of the States, as the case may be, or any

other interest which in the opinion of the Central Government or, as the case may be, of the State Government is to be represented ;

(*e*) two persons to be nominated by the Central Government to represent the companies or corportions owned, controlled or managed by the Central Government and situated in the participating Union territory or territories and two persons to be nominated by the Central Government to represent the companies or corporations owned, controlled or managed by the participating State Governments ;

(*f*) a full-time member-secretary qualified in public health engineering and having administrative experience, to be appointed by the Central Government.

(3) When a Joint Board is constituted in pursuance of an agreement under clause (*b*) of sub-section (1) of section 13, the provisions of sub-section (4) of section 4 shall cease to apply in relation to the Union territory for which the Joint Board is constituted.

(4) Subject to the provision of sub-section (3), the provisions of sub-section (3) of section 4 and sections 5 to 12 (inclusive) shall apply in relation to the Joint Board and its member-secretary as they apply in relation to a State Board and its member-secretary.

(5) Any reference in this Act to the State Board shall, unless the context otherwise requires, be construed as including a Joint Board.

Special Provisions Relating to Giving of Directions

15. Notwithstanding anything contained in this Act where any Joint Board is constituted under section 13,—

(*a*) the Government of State for which the Joint Board is constituted shall be competent to give any direction under this

Act only in case where such direction relates to a matter within the exclusive jurisdiction of the State ;

(*b*) the Central Government alone shall be competent to give any direction under this Act where such direction relates to a matter within the territorial jurisdiction of two or more States or pertaining to a Union territory.

CHAPTER IV

POWERS AND FUNCTIONS OF BOARDS

Functions and Central Board

16. (1) Subject to the provisions of this Act, the main function of the Central Board shall be to promote cleanlines of streams and wells in different areas of the States.

(2) In particular and without prejudice to the generality of the foregoing function, the Central Board may perform all or any of the following functions namely :—

(*a*) advice the Central Government on any matter concerning the prevention and control of water pollution ;

(*b*) co-ordinate the activities of the State Boards and resolve disputes among them ;

(*c*) provide technical assistance and guidance to the State Boards, carry out and sponsor investigations and research relating to problems of water pollution and prevention, control or abatement of water pollution ;

(*d*) plant and organise the training of persons engaged or to be engaged in programmes for the prevention, control or abatment of water pollution on such terms and conditions as the Central Board may specify ;

(*e*) organise through mass media a comprehensive programme regarding the prevention and control of water pollution ;

(*f*) collect, compile and publish technical and statistical data relating to water pollution and the measures devised for its effective prevention and control and prepare manuals, codes or guides relating to treatment and disposal of sewage and trade effluents and eliminate information concerned therewith ;

(*g*) lay down, modify or annul, in consulation with the State Government concerned, the standards for a stream or well ;

Provided that different standards may be laid down for the same stream or well or for different streams or wells, having regard to the quality of water, flow characteristics of the stream or well and the nature of the use of the water in such stream or well or streams or wells :

(*h*) plan and cause to be executed a nation-wide programme for the prevention, control or abatment of water pollution ;

(*i*) perform such other functions as may be prescribed.

(3) The Board establish or recognise a laboratory or laboratories to enable the Board to perform its functions under this section efficiently, including the analysis of samples of water from any stream or well or of samples of any sewage or trade effluents.

Functions of State Board

17. (1) Subject to the provisions of this Act, the functions of a State Board shall be :—

(*a*) to plan a comprehensive programme for the prevention, control or abatment of pollution of streams and wells in the State and to secure the execution thereof ;

(*b*) to advise the State Government on any matter concerning the prevention, control or abatment of water pollution ;

(*c*) to collect and disseminate information relating to water pollution and the prevention, control or abatment thereof ;

(*d*) to encourage, conduct and participate in investigation and research relating to problems of water pollution and prevantion, control or abatment of water pollution ;

(*e*) to collaborate with the Central Board in organising the training of persons engaged or to be engaged in progrmmes relating to prevention, control of abatment of water pollution and to organise mass education programmes relating thereto ;

(*f*) to inspect sewage or trade effluents, works and plants for the treatment of sewage and trade effluents and to review plans, specifications or other data relating to plans set up for the treatment of water, works for the purification thereof and the system for the disposal of sewage or trade effluents or in connection with the great of any consent as required by this Act ;

(*g*) to lay down, modify or annul effluent standards for the sewage and trade effluents and for the quality of receiving water (not being water in an inter-State stream) resulting from the discharge of effluents and to classify waters of the State ;

(*h*) to evolve economical and reliable methods of treatment of sewage and trade effluents, having regard to the peculiar conditions of soils, climate and water resources of different regions and more especially the prevailing flow characteristics of water in streams and wells which render it impossible to attain even the minimum degree of dilution ;

(*i*) to evolve methods of utilisation of sewage and suitable trade effluents in agriculture ;

(*j*) to evolve efficient methods of disposal of sewage and trade effluents on land, as are necessary on account of the predominant conditions of scan stream flows that do not

provide for major part of the year the minimum degree of dilution ;

(*k*) to lay down standards of treatment of sewage and trade effluents to be discharged into any particular stream taking into account the minimum fair weather dilution available in that stream and the tolerance limits of pollution permissible in the water of the stream, after the discharge of such effluents ;

(*l*) to make, vary or revoke any order—

(*i*) for the prevention, control or abatment of discharges of waste into streams or wells ;

(*ii*) requiring any person concerned to construct new systems for the disposal of sewage and trade effluents or to modify, alter to extend any such existing system or to adopt such remedial measures as are necessary to prevent, control or abate water pollution ;

(*m*) to lay down effluent standards to be complied with by persons while causing discharge of sewage or sullage or both and to lay down, modify or annul effluent standards for the sewage and trade effluents ;

(*n*) to advise the State Government with respect to the location of any industry the carrying on of which is likely to pollute a stream or well ;

(*o*) to perform such other functions as may be prescribed or as may, from time to time, be entrusted to it by the Central Board or the State Government.

(2) The Board may establish or recognise a laboratory or laboratories to enable the Board to perform its functions under this sections efficiently, including the analysis of samples of water from any stream or well or of any sewage or trade effluents.

Powers to Give Directions

18. In the performance of its functions under this Act—

(a) the Central Board shall be bound by such directions in writting as the Central Government may give to it ; and

(b) every State Board shall be bound by such directions in writing as the Central Board or the State Government may give to it :

Provided that where a direction give by the State Government is inconsistent with the direction given by the Central Board, the matter shall be referred to the Central Government for its decision.

CHAPTER V

PREVENTION AND CONTROL OF WATER POLLUTION

Power of State Government to Restrict the Application of the Act to Certain Areas

19. (1) Notwithstanding anything contained in this Act, if the State Government, after consultation with, or on the recommendation of, the State Board, is of opinion that the provisions of this Act need not apply to the entire State, it may, by notification in the Official Gazette, restrict the application of this Act to such area or areas as may be declared therein as water pollution, prevention and control area or areas and thereupon the provisions of this Act shall apply only to such area or areas.

(2) Each water pollution, prevention and control area may be declared either by reference to a map or by reference to the line of any watershed or the boundary of any district or partly by one method and partly by another.

(3) The State Government may, by notification in the Official Gazette,—

(a) alter any water pollution, prevention and control area whether by way of extentsion or reduction ; or

(b) define a new water pollution, prevention and control area in which may be merged one or more water pollution, prevention and control areas, or any parts thereof.

Power to Obtain Information

20. (1) For the purpose of enabling a State Board to perform the funcitons conferred on it by or under this Act, the State Board or any officer empowered by it in that behalf, or may make surveys of any area and gauge and keep records of the flow or volume and other characteristics of any stream or well in such area, and may take steps for the measurement and recording of the rainfall in such area or any part thereof and for the installation and maintenance for those purposes of gauges or other apparatus and works connected therewith, and carry out stream surveys and may take such other steps as may be necessary in order to obtain any information required for the purposes aforesaid.

(2) A State Board may give directions requiring any person who in its opinion is abstracting water from any such stream or well in the area in quantities which are substantial in relation to the flow or volume of that stream or well or is discharge sewage or trade effluent into any such stream or well, to give such information as to the abstraction or the discharge at such times and in such form as may be specified in the direction.

Without prejudice to the provisions of sub-section (2), a State Board with a view to preventing or controlling pollution of water, give directions requiring any person in charge of any establishment where any industry or trade is carried on, to furnish to it information regarding the construction, installation or operation of such establishment or of any disposal system or of any extension or addition thereto in such establishment and such other particulars as may be prescribed.

Fower to take Samples of Effluents and Procedure to be Followed in Connection therewith

21. (1) A State Board or any officer empowered by it in this behalf shall have power to take for the purpose analysis samples of water from any stream or well or samples of any sewage or trade

effluent which is passing from any plant or vessel or from or over any place into any such stream or well.

(2) The result of any analysis of a sample of any sewage or trade effluent taken under sub-section (1) shall not be admissible in evidence in any legal proceeding unless the provisions of sub-sections (3), (4) and (5) are complied with.

(3) Subject to the provisions of sub-sections (4) and (5), when a sample (composite or otherwise as may be warranted by the process used) any sewage or trade effluent is taken for analysis under sub-section (1), the person taking the sample shall—

(*a*) serve on the person in charge of, or having control over, the plant of vessel or in occupation of the place (which person is hereinafter referred to as the occupier) or any agent of such occupier, a notice, then and there in such form as may be described of this intention to have it so analysed ;

(*b*) In the presence of the occupier or his agent, divide the sample into two parts ;

(*c*) cause each part to be placed in a container which shall be marked and scaled and shall also be signed both by the person taking the sample and the occupier or his agent ;

(*d*) send one container forthwith,—

(*i*) in a case where such sample is taken from any area situated in a Union territory, to the laboratory established or recognised by the Central Board under section 16 ; and

(*ii*) in any other case, to the laboratory established or recognised by the State Board under section 17 ;

(*e*) on the request of the occupier or his agent, send the second container,—

(*i*) in a case where such sample is taken from any area situated in a Union territory, to the laboratory esta-

blished or specified under sub-section (1) of section 51 ; and

(*ii*) in any other case, to the laboratory established or specified under sub-section (1) of section 52.

(4) When a sample of any sewage or trade effluent is taken for analysis under sub-section (1) and the person taking the sample serves on the occupier or his agent, a notice under clause (*a*) of sub-section (3) and the occupier or his agent wilfully absents himself, then, the sample so taken shall be placed in a container which shall be marked and sealed and shall also be signed by the person taking the sample and the same shall be sent forthwith by such person for analysis to the laboratory referred to in sub-clause (*i*) or sub-clause (*ii*), as the case, may be, of clause (*e*) of sub-section (3) and such person shall inform the Government analyst appointed under sub-section (1) or sub-section (2), as the case may be, of section 53, in writting about the wilful absence of the occupier or his agent.

(5) When a sample of any sewage or trade effluent is taken for analysis under sub-section (1) and the person taking the sample serves on the occupier or his agent a notice under clause (*a*) of sub-section (3) and the occupier or his agent who is present at the time of taking the sample does not make a request for dividing the sample into two parts as provided in clause (*b*) of sub-section (3), then the sample so taken shall be placed in a container which shall be marked and sealed and shall also be signed by the person taking the sample and the same shall be sent forthwith by such person for analysis to the laboratory referred in sub-clause (*i*) or sub-clause (*ii*), as the case may be, of clause (*1*) to sub-section (3).

Reports of the Result of Analysis on Samples Taken Under Sestion 21

22. (1) Where a sample of any sewage or trade effluent has been sent for analysis to the laboratory established or recognised by the Central Board or, as the case may be, the State Board, the concerned Board analyst appointed under sub-section (3) of section 53

shall analyse the sample and submit a report in the prescribed form of the result of such analysis in triplicate to the Central Board or the State Board, as the case may be.

(2) On receipt of the report under sub-section (1), one copy of the report shall be sent by the Central Board or the State Board, as the case may be to the occupier or his agent referred to in section 21, another copy shall be preserved for production before the court in case any legal proceedings are taken against him and the other copy shall be kept by the concerned Board.

(3) Where a sample has been sent for analysis under clause (*e*) of sub-section (3) or sub-section (4) of section 21 to any laboratory mentioned therein, the Government analyst referred to in that sub-section shall analyse the sample and submit a report in the prescribed form of the result of the analysis in triplicate to the Central Board or, as the case may be, the State Board which shall comply with the provisions of sub-section (2).

(4) If there is any inconsistency or discrepancy between, or variation in the results of, the analysis carried out by the labatory or established or recognised by the Central Board or the State Board, as the case may be and that of the laboratory established or specified under section 51 or section 52, as the case may be, the report of the latter shall prevail.

(5) Any cost incurred in getting any sample analysed at the request of the occupier or his agent shall be payable by such occupier or his agent and in case of default the same shall be recoverable from him as arrears of land revenve or of public demand.

Power of Entry and Inspection

(1) Subject to the provisions of this section, any person empowered by a State Board in this behalf shall have a right at any time to enter, the such assistance as he considers necessary, any place—

(*a*) for the purpose of performing any of the functions of the Board entrusted to him ;

(*b*) for the purpose of determining whether and it so in what manner, any such functions are to be performed or whether any provisions of this Act or the rules made thereunder or any notice, order, direction or authorisation served, made, given, or granted under this Act is being or has been complied with ;

(*c*) for the purpose of examining any plant, record, register, document or any other material object or for conducting a search of any place in which he has reason to believe that an offence under this Act or the rules made thereunder has been or is being or is about to be committed and for seizing any such plant, record, register, document or other material object, if he has reason to believe that it may furnish evidence of the commission of an offence punishable under this Act or the rules made thereunder :

Provided that the right to enter under this sub-section for the inspection of a well shall be exercised only at reasonable hours in a case where such well is situated in any premises used for residential purposes and the water thereof is used exclusively for domestic purposes.

(2) The provisions of the Code of Criminal Procedure, 1898 (5 of 1898) or, in relation to the State of Jammu and Kashmir, the provisions of any corresponding law in force in that State, shall, so far as may be, apply to any search or seizure under this section as they apply to any search or seizure made under the authority of a warrant issued under section 98 of the said Code, or, as the case may be, under the corresponding provisions of the said law.

Explanation.—For the purposes of this section, "place" includes vessel.

Prohibition on use of Stream or well for Disposal of Polluting matter, etc.

24. (1) Subject to the provisions of this section,—

(*a*) no person shall knowingly cause or permit any poisonous, noxious or polluting matter determined in accordance with such standards as may be laid down by the State Board to enter (whether directly or indirectly) into any stream or well ; or

(*b*) no person shall knowingly cause or permit to enter into any stream any other matter which may tend, either directly or in combination with similar matters, to impede the proper flow of the water of the stream in a manner leading or likely to lead to a substantial aggravation of pollution due to other causes or of its consequences.

(2) A person shall not be guilty of an offence under sub-section (1), by reason only of having done or caused to be done any of the following acts, namely :—

(*a*) constructing, improving or maintaining in or across or on the bank or bed of any stream any building, bridge, weir, dam, sluice, dock, pier, drain or sewer or other permanent works which he has a right to construct, improve or maintain ;

(*b*) depositing any materials on the bank or in the bed of any stream for the purpose of reclaiming land or for supporting, repairing or protecting the bank or bed of such stream provided such materials are not capable of polluting such stream ;

(*c*) putting into any stream, any sand or gravel or other natural deposit which has flowed from or been deposited by the current of such stream ;

(*d*) causing or permitting, with the consent of the State Board, the deposit accumulated in a well, pond or reservoir on enter into any stream.

(3) The State Government may, after consultation with, or to the recommendation of, the State Board, exempt, by notification in

the Official Gazette, any person from the operation of sub-section (1) subject to such conditions if any, as may be specified in the notification and any condition so specified may by a like notification be altered, varied or amended.

Restrictions on New Outlets and New Discharges

(1) Subject to the provisions of this section no person shall, without the previous consent of the State Board, bring into use any new or altered outlet for the discharge of sewage or trade effluent into a stream or well or begin to make any new discharge of sewage or trade effluent into a stream or well.

(2) The application for consent of the State Board under sub-section (1) shall be made in the prescribed form and shall contain particulars regarding the proposed construction, installation or operation of the industrial or commercial establishment or of any treatment and disposal system or of any extension or addition thereto and such other particulars as may be prescribed.

(*a*) in State Board may make such inquiry as it may deem fit in respect of the application for consent referred to in sub-section (1) and in making any such inquiry shall follow such procedure as may be prescribed.

(*b*) the State Board may grant its consent referred to in sub-section (1), subject to such conditions as it may impose, being—

(*c*) on the case of a new or altered outlet, conditions as to the point of discharge into the stream or well or the construction of the outlet or as to the use of that outlet or any other outlet for sewage or trade effluent from the same land or premises ; and

(*d*) in the case of a new discharge, conditions as to the nature and composition, temperature, volume or rate of discharge of the effluent from the land or premises fr ›m which the new discharge is to be made,

and any such conditions imposed shall be binding on any person using the outlet or discharging the effluent from the land or premises aforesaid.

(5) Where, without the consent of the State Board, a new or altered outlet is brought into use for the discharge of sewage or trade effluent in to a stream or well or a new discharge of sewage or trade effluent is made ; the State Board may serve on the person using the outlet or making the discharge, as the case may be, a notice imposing any such condition as it might have imposed on an application for its consent in respect to such outlet or discharge.

(6) Every State Board shall maintain a register containing such particulars of the conditions imposed under this section in relation to outlets or in relation to effluent from land or premises in its jurisdiction and as are for the time being in force (other than the conditions to be satisfied before an outlet is brought into use or a new discharge is made) and so much of the register as relates to any outlet, or to any effluent from such land or premises shall be open to inspection at all reasonable hours by any person interested in, or affected by, the outlet, or in the land or premises, as the case may be, or by any person authorised by him in this behalf and the conditions so contained in such register shall be conclusive proof that the consent was granted subject to such conditions.

(7) The consent referred to in sub-section (1) shall, unless given or refused earlier, be deemed to have been given unconditionally on the expiry of a period of four months of the making of an application in this behalf complete in all respects to the State Board.

(8) For the purposes of this section and sections 27 and 30,—

(*a*) the expression "new or altered outlet" means any outlet which is wholly or partly constructed on or after the commencement of this Act or which (whether so constructed or not) is substantially altered after such commencement ;

(*b*) the expression "new discharge" means a discharge which is not, as respects the nature and composition, temperature, volume and rate of discharge of the effluent substantially a continuation of a discharge made within the preceding twelve months (whether by the same or a different outlet), so however that a discharge which is in other respects a continuation of previous discharge made as aforesaid shall not be deemed to be a new discharge by reason of any reduction of the temperature or volume or rate of discharge of the effluent as compared with the previous discharge.

Provision Regarding Existing Discharge of Sewage or Trade effluent

26. Where immediately before the commencement of this Act any person was discharging any sewage or trade effluent into a stream or well, the provisions of section 25 shall, so far as may be, apply in relation to such person as they apply in relation to the person referred to in that section subject to the modification that the application for consent to be made under sub-section (2) of that section shall be made within a period of three months of the constitution of the State Board.

Refusal or Withdrawal of Consent by State Board

27. (1) State Board shall not grant its consent to the bringing into use of a new or altered outlet unless the outlet is so constructed as to comply with any conditions imposed by the Board to enable it to exercise its right to take samples of the effluent.

(2) A State Board may from time to time review any condition imposed under section 25 (other than a condition to be satisfied before an outlet is brought into use or a new discharge is made), or under section 26 and may serve on the person using the outlet or making the discharge, as the case may be, a notice making any reasonable variation of or revoking such condition.

(3) Any condition imposed under section 25 or section 26 shall be subject to any variation made under sub-section (2) and shall continue in force until revoked under that sub-section.

Appeals

28. (1) Any person aggrieved by an order made by the State Board under section 25, section 26 or section 27 may, within thirty days from the date on which the order is communicated to him, prefer an appeal to such authority (hereinafter referred to as the appellate) authority as the State Government may think fit to constitute :

Provided that the appellate authority may entertain the appeal after the expiry of the said period of thirty days if such authority is satisfied that the appellant was prevented by sufficient cause from filing the appeal in time.

(2) An appellate authority shall consist of three persons.

(3) The form and manner in which an appeal may be preferred under sub section (1), the fees payable for such appeal and the procedure to be followed by the appellate authority shall be such as may be prescribed.

(4) On receipt of an appeal preferred under sub-section (1), the appellate authority shall, after giving the appellant and the State Board an opportunity of being heard, dispose of the appeal as expeditiously as possible.

(5) If the appellate authority determines that any condition imposed, or the variation of any condition, as the case may be, was unreasonable, then,—

(*a*) where the appeal is in respect of the unreasonableness of any condition imposed, such authority may direct either that the condition shall be treated as annulled or that there shall be substituted for it such condition as appears to it to be reasonable ;

(*b*) where the appeal is in respect of the unreasonableness of any variation of a condition, such authority may direct either that the condition shall be treated as continuing in force unvaried or that it shall be varied in such manner as appears to it to be reasonable.

Revision

29. (1) The State Government may at any time either of its own application made to it in this behalf, of on all call for the records of any case where an order has been made by the State Board under section 25, section 26 or section 27 for the purpose of satisfying itself as to the legality or propriety of any such order and may pass such order in relation thereto as it may think fit.

Provided that the State Government shall not pass any order under this sub-section without affording the State Board and the person who may be affected by such order a reasonable opportunity of being heard in the matter.

(2) The State Government shall not revise any order made under section 25, section 26 or section 27 where an appeal against that order lies to the appellate authority, but has not been preferred or where an appeal has been preferred such appeal is pending before the appelate authority.

Power of State to carry out certain works

30. (1) Where under this Act any condition have been imposed on any person for bringing into use any new or altered outlet for the discharge of sewage or trade effluent into a stream or well or for making any new discharge of sewage or trade effluent into a stream or well or on any person who, immediately before the commencement of this Act, was discharging any sewage or trade effluent in a stream or well and such conditions require such person to execute any work in connection therewith and such work has not been executed within such time as may be specified in this

behalf, the State Board may serve on the person concerned a notice requiring him within such time (not being less than thirty days) as may be specified in the notice to execute the work specified therein.

(2) If the person concerned fails to execute the work as required in the notice referred to in sub-section (1), then after the expiration of the time specified in the said notice, the State Board may itself execute or cause to be executed such work.

(3) All expenses incurred by the State Board for the execution of the aforesaid work, together with interest, at such rate as the State Government may, be order, fix, from the date when a demand for the expenses is made until it is paid, may be recovered by that Board from the person concerned, as arrears of land revenue, or of public demand.

Furnishing of Information to State Boards and Other Agencies in Certain Cases

31. (1) If at any place where any industry or trade is being carried on, due to accident or other unforseen act or event, any poisonous, noxious or polluting matter is being discharged, or is likely to be discharged into a stream or well and, as a result of such discharge, the water in such stream or well is being polluted, or is likely to be polluted, then, the person in charge of such place shall forthwith intimate the occurrence of such accident act or event to the State Board and to such other authorities or agencies as may be prescribed.

(2) Where any local authority operates any sewerage system or sewage works, the provisions of sub-section (1) shall apply to such local authority as they apply in relation to the person in charge of the place where any industry or trade is being corried on.

Emergency Measures in Case of Pollution of Stream or Well

32. (1) Where it appears to the State Board that any poisonous, noxious polluting matter is present in any stream or

well or has entered into that stream or well due to any accident or other unforeseen act or event, and if the Board is of opinion that it is necessary or expedient to take immediate action, it may for reasons to be recorded in writing, carry out such operations as it may consider necessary for all or any of the following purposes, that is to say,—

(*a*) removing that matter from the stream or well and disposing it of in such manner as the Board considers appropriate ;

(*b*) remedying or mitigating any pollution caused by its presence in the stream or well ;

(*c*) issuing orders immediately restraining or prohibiting the person concerned from discharging any poisonous, noxious or polluting matter into the stream or well, or from making insanitary use of the stream or well.

(2) The power conferred by sub-section (1) does not include the power to construct any works other than works of a temporary character which are removed on or before the completion of the operation.

Power of Board to Make Application to Courts for Restaining Apprehended Pollution of Water in Streams or Wells

33. (1) Where it is apprehended by a Board that the water in any stream or well is likely to be polluted by reason of the disposal of any matter therein or of any likely disposal of any matter therein or otherwise the Board may make an application to a court, not inferior to that of presidency Magistrate or a Magistrate of the first class, for restraining person who is likely to cause such pollution from so causing.

(2) On receipt of an application under sub-section (1) the court may make such order as it deems fit.

(3) Where under sub-section (2) the court makes an order restraining person from polluting the water in any stream or well, it may in that order—

(*i*) direct the person who is likely to cause or has caused the pollution of the water in the stream or well, to desist from taking such action as is likely to cause pollution or, as the case may be, to remove from such stream or well, such matter, and

(*ii*) authorise the Board, if the direction under clause (*i*) being a direction for the removal of any matter from such stream or well) is not complied with by the person to whom such direction is issued, to undertake the removal and disposal of the matter in such manner as may be specified by the court.

(4) All expenses incurred by the Board in removing and matter in pursuance of the authorisation under clause (*ii*) of sub section (3) or in the disposal of any such matter may be defrayed out of any money obtained by the Board from such disposal and any balance outstanding shall be recoverable from the person concerned as arrears of land revenue or of public demand.

CHAPTER VI

FUNDS, ACCOUNTS AND AUDIT

Contributions by Central Government

34. The Central Government may, after due appropriation made by Parliament by law in this behalf, make in each financial year such contributions to the Central Board as it may think necessary to enable the Board perform it functions under this Act.

Contributions by State Government

35. The State Government may after due, appropriation made by the Legislature of the State by law in this behalf, make in each financial year such contributions in the State Board as it may think necessary to enable that Board to perform its functions under this Act.

Fund of Central Board

36. (1) The Central Board shall have its own fund, and all sums which may, from time to time, be paid to it by the Central Government and all other receipts (by way of gifts, grants, donations, benefactions or otherwise) of that Board shall be carried to the fund of the Board and all payments by the Board shall be made therefrom.

(2) The Central Board may expend such sums as it thinks fit for performing its functions under this Act, and such sums shall be treated as expenditure payable out of the fund of that Board.

Fund of State Board

37. (1) The State Board shall have its own fund, and the sums which may, from time to time, be paid to it by the State Government and all other receipts (by way of gifts, grants, donations, benefactions or otherwise) of that Board shall be carried to the fund of the Board and all payments by the Board shall be made therefrom.

(2) The State Board may expend such sums as it thinks fit for performing its functions under this Act. and such sums shall be treated as expenditure payable out of the fund of that Board.

Budget

38. The Central Board or, as the case may be, the State Board shall, during each financial year prepare, in such form and at such time as may be prescribed, a budget in respect of the financial year next ensuing showing the estimated receipt and expenditure, and copies thereof shall be forwarded to the Central Government or, as the case may be, the State Government.

Annual Report

39. (1) The Central Board shall during each financial year, prepare, in such form and at such time as may be prescribed, an

annual report giving a true and full account of its activities during the previous financial year and copies thereof shall be forwarded to the Central Government and that Government shall cause every such report to be laid before both Houses of Parliament within six months of the date on which it is received by that Government.

(2) The State Board shall during each financial year, prepare, in such form and at such time as may be prescribed, an annual report giving a true and full account of its activities during the previous financial year and copies thereof shall be forwarded to the State Government and that Government shall cause every such report to be laid before the State Legislature within a period of six months of the date on which it is received by that Government.

Accounts and Audit

40. (1) Every Board shall maintain proper accounts and other relevant records and prepare an annual statement of accounts in such form as may be prescribed by the Central Government or, as the case may be, the State Government.

(2) The accounts of the Board shall be audited by an auditor duly qualified to act as an auditor of companies under section 226 of the Companies Act, 1956 (1 of 1956).

(3) The said auditor shall be appointed by the Central Government or, as the case may be, the State Government on the advice of the Comptroller and Auditor General of India.

(4) Every auditor appointed to audit the accounts of the Board under this Act shall have the right to demand the production of books, accounts, connected vouchers and other documents and papers and to inspect any of the office of the Board.

(5) Every such auditor shall send a copy of his report together with an audited copy of the accounts to the Central Government or, as the case may be, the State Government.

The Central Government shall, as soon as may be after the receipt of the audit report under sub-section (5), cause the same to be laid before Houses of Parliament.

The State Government shall, as soon as may be after the receipt of the audit report under sub-section (5), cause the same to be laid before the state Legislature.

CHAPTER VII
PENALTIES AND PROCEDURE

Failure to comply with directions under sub-section (2) or sub-section (3) of section 20 or orders issued under clause (c) of sub-section (1) or section 32.

41. (1) Whoever fails to comply with any direction given under snb-section (2) or sub-section (3) of section 20 within such time as may be specified in the direction of fails to comply with any orders issued under clause (*c*) of sub-section (1) of section 32 shall, on conviction, be punishable with imprisonment for a term which may extend to three months or with fine which may extend to five thousand rupees or with both and in case the failure continues, with an additional fine which may extend to one thousand rupees for every day during which such failure continues after the conviction for the first such failure.

(2) Whoever fails to comply with any direction issued by a court under sub-section (2) of section 33 shall, on conviction, be punishable with imprisonment for a term which may extend to three months or with fine which may extend to five thousand rupees or with both and in case the failure continues, with an additional fine which may extend to one thousand rupees for every day during which such failure continues or the first such failure.

Penalty for Certain Acts

42. (1) Whoever—

(*a*) destroys, pulls down, removes, injures or defaces any pillar, post or stake fixed in the ground or any notice or other matter put up, inscribed or placed, by or under the authority of the Board, or

(*b*) obstructs any person acting under the orders or directions of the Board from exercising his powers and performing his functions under this Act, or

(*c*) damages any works or property belonging to the Board, or

(*d*) fails to furnish to any officer or other employee of the Board any information required by him for the purpose of this Act, or

(*e*) fails to intimate the occurrence of any accident or other unforeseen act or event under section 31 to the Board and other authorities or agencies as required by that section, or

(*f*) in giving any information which he is required to give under this Act, knowingly or wilfully makes a statement which is false in any material particular.

(*g*) for the purpose of obtaining any consent under section 25 or section 26, knowingly or wilfully makes a statement which is false in any material particular,

and be punishable with imprisonment for a term which may extend to three months or with fine which may extend to one thousand rupees or the both.

(2) Where for the grant of a consent in pursuance of the provisions of section 25 or section 26 the use of a meter or gauge or other measure or monitoring device is required and such device is used for the purposes of those provisions, any person who knowingly or wilfully alters or interferes with that device so as to prevent it from monitoring or measuring correctly shall be punishable with imprisonment for a term which may extend to three months or with fine which may extend to one thousand rupees or with both.

Penalty for Contravention of Provisions of Section 24

Whoever contravenes the provisions of section 24 shall be punishable with imprisonment for a term which shall not be less than six months but which may extend to six years and with fine.

Penalty for Contravention of Section 25 or Section 26

44. Whoever contravenes the provisions of section 25 or section 26 shall be punishable with imprisonment for a term which shall not be less than six months but which may extend to six years and with fine.

Enhanced Penalty after Previous Conviction

45. If any person who has been convicted of any offence under section 24 or section 25 or section 26 is again found guilty of an offence involving contravention of the same provision, he shall, on the second and on every subsequent conviction, be punishable with imprisonment for a term which shall not be less than one year but which may extend to seven years and with fine :

Provided that for the purpose of this section no cognizance shall be taken of any conviction made more than two years before the commission of the offence which is being punished.

Publication of Names of Offenders

46. If any person convicted of an offence under this Act commits a like offence afterwards it shall be lawful for the court before which the second or subsequent conviction takes place to cause the offender's name and place of residence, the offence and the penalty imposed to be published at the offender's expense in such newspapers or in such other manner as the court may direct and the expenses of such publication shall be deemed to be part of the cost attending the conviction and shall be recoverable in the same manner as a fine.

Offences by Companies

47. (1) Where an offence under this Aet has been committed by a company, every person who at the time the offence was committed was in charge of, and was responsible to the company for the conduct of, the business of the company as well as the company, shall be deemed to be guilty of the offence and shall be liable to be proceeded against and punished accordingly :

Provided that nothing contained in this sub-section shall render any such person liable to any punishment provided in this Act if he proves that the offence was committed without his knowledge or that he exercised all due diligence to prevent the commission of such offence.

(2) Notwithstanding anything contained in sub-section (1), where an offence under this Act has been committed by a company and it is proved that the offence has been committed with the consent or connivance of, or is attributable to any neglect on the part of, any director, manager, secretary or other officer of the company, such director, manager, secretary or other officer shall also be deemed to be guilty of that offence and shall be liable to be proceeded against and punished accordingly.

Explanation—For the purposes of this section,—

(*a*) "company" means any body corporate, and includes a firm or other association of individuals ; and

(*b*) "director" in relation to a firm means a partner in the firm.

Offences by Government Departments

48. Where an offence under this Act has been committed by any Department of Government, the Head of the Department shall be deemed to be guilty of the offence and shall be liable to be proceeded against and punished accordingly :

Provided that nothing contained in this section shall render such Head of the Department liable to any punishment if he proves

that the offence was committed without his knowledge or that he exercised all due diligence to prevent the commission of such offence.

Cognizance of Offences

49. (1) No court shall take cognizance of any offence under this Act except on a complaint made by, or with the previous sanction in writing of the State Board, and no court inferior to that of a Presidency Magistrate or a Magistrate of the first class shall try any offence punishable under this Act.

(2) Notwithstanding anything contained in section 32 of the Code of diminal Procedure, 1898 (5 of 1898), it shall be lawful for any Magistrate of the first class or for any Presidency Magistrate to pass a sentence of imprisonment for a term exceeding two years or of fine exceeding two thousand rupees on any person convicted of an offence punishable under this Act.

Members, Officers and Servants of Board to be Public Servants

50. All members, officers and servants of a Board when acting or purporting to act in pursuance of any of the provisions of this Act and the rules made thereunder shall be deemed to be public servants within the meaning of section 21 of the Indian Penal Code (45 of 1860).

CHAPTER VIII
MISCELLANEOUS

Central Water Laboratory

51. (1) The Central Government may, by notification in the Official Gazette,—

(*a*) establish a Central Water Laboratory ; or

(*b*) specify any laboratory or institute as a Central Water Laboratory, to carry out the functions entrusted to the Central Water Laboratory under this Act.

(2) The Central Government may, after consultation with the Central Board, make rules prescribing—

(*a*) the functions of the Central Water Laboratory ;

(*b*) the procedure for the submission to the said laboratory of samples of water or of sewage or trade effluent for analysis or tests, the form of the laboratory's report thereunder and the fees payable in respect of such report ;

(*c*) such other matters as may be necessary or expedient to enable that laboratory to carry out its functions.

State Water Laboratory

52. (1) The State Government may, by notification in the Official Gazette,—

(*a*) establish a State Water Laboratory ; or

(*b*) specify any laboratory or institute as a State Water Laboratory, to carry out the functions entrusted to the State Water Laboratory under this Act.

(2) The State Government may, after consultation with the State Board, make rules prescribing—

(*a*) the functions of the State Water Laboratory ;

(*b*) the procedure for the submission to the said laboratory of samples of water or of sewage or trade effluent for analysis or tests, the form of the laboratory's report thereon and the fees payable in respect of such report ;

(*c*) such other matters as may be necessary or expedient to enable that laboratory to carry out its functions.

Analysis

53. (1) The Central Government may, by notification in the Official Gazette, appoint such persons as it thinks fit and having the prescribed qualifications to be Government analysts for the purpose of analysis of samples of water or of sewage or trade effluent sent for

analysis to any laboratory established or specified under sub-section (1) of section 51.

(2) The State Government may, by notification in the Official Gazette, appoint such persons as it thinks fit and having the prescribed qualifications to be Government analysts for the purpose of analysis of samples of water or of sewage or trade effluent sent for analysis to any laboratory established or specified under sub-section (1) of section 52.

(3) Without prejudice to the provisions of sub-section (3) of section 12, the Central Board or, as the case may be, the State Board may, by notification in the Official Gazette, and with the approval of the Central Government or the State Government, as the case may be, appoint such persons as it thinks fit and having the prescribed qualifications to be Board analysts for the purpose of analysis of samples of water or of sewage or trade effluent sent for analysis to any laboratory established or recognised under section 16, or, as the case may be, under section 17.

Reports of Analysis

Any document purporting to be a report signed by a Government analyst or as the case may be, a Board analyst may be used as evidence of the lacts stated therein in any proceeding under this Act.

Local Authorities to Assist

All local authorities shall render such help and assistance and furnish such information to the Board as it may require for the discharge of its functions, and shall make available to the Board for inspection and examination such records, maps, plans and other documents as may be necessary for the discharge of its functions.

Compulsory Acquisition of Land for the State Board

56. Any land required by a State Board for the efficient performance of its functions under this Act shall be deemed to be needed for a public purpose and such land shall be acquired for the

State Board under the provisions of the Land Acquisition Act, 1894 (1 of 1894), or under any other corresponding law for the time being in force.

Returns and Reports

57. The Central Board shall furnish to the Central Government, and a State Board shall furnish to the State Government and to the Central Board such reports, returns, statistics, accounts and other information with respect to its fund or activities as that Government, or, as the case may be, the Central Board may, from time to time, require.

Bar of Jurisdiction

58. No civil court shall have jurisdiction to entertain any suit or proceeding in respect of any matter which an appellate authority constituted under this Act is empowered by or under this Act to determine, and no injunction shall be granted by any court or other authority in respect of any action taken or to be taken in pursuance of any power conferred by or under this Act.

Protection of Action Taken in Good Faith

59. No suit or other legal proceedings shall lie against the Government or any officer of Government or any member or officer of a Board in respect of anything which is in good faith done or intended to be done in pursuance of this Act or rules made thereunder.

Over-riding Effect

60. The provisions of this Act shall have effect notwithstanding anything inconsistent therewith contained in any enactment other than this Act.

Power of Central Government to Supersede the Central Board and Joint Boards

61. (1) If at any time the Central Government is of opinion—

(*a*) that the Central Board or any Joint Board has persistently made default in the performance of the functions imposed on it by or under this Act ; or

(*b*) that circumstances exist which render it necessary in the public interest so to do,

the Central Government may, by notification in the Official Gazette, supersede the Central Board or such Joint Board, as the case may be, for such period, not exceeding one year, as may be specified in the notification :

Provided that before issuing a notification under this sub-section for the reasons mentioned in clause (*a*), the Central Government shall give a reasonable opportunity to the Central Board or such Joint Board, as the case may be, to show cause why it should not be superseded and shall consider the explanations and objections, if any, of the Central Board or such Joint Board, as the case may be.

(2) Upon the publication of a notification under sub-section (1) superseding the Central Board or any Joint Board,—

(*a*) all the members shall, as from the date of supersession vacate their offices as such ;

(*b*) all the powers, functions and duties which may, by or under this Act, be exercised, performed or discharged by the Central Board as such Joint Board shall, until the Central Board or the Joint Board, as the case may be, is reconstituted under sub-section (3) be exercised, performed or discharged by such person or persons as the Central Government may direct ;

(*c*) all property owned or controlled by the Central Board or such Joint Board shall until the Central Board or the Joint Board, as the case may be, is reconstituted under sub-section (3) vest in the Central Government.

(3) On the expiration of the period of supersession specified in the notification issued under sub-section (1), the Central Government may—

(*a*) extend the period of supersession for such further term, not exceeding six months, as it may consider necessary ; or

(*b*) reconstitute the Central Board or the Joint Board, as the case may be, by fresh nomination or appointment, as the case may be, and in such case any person who vacated his office under clause (*a*) of sub-section (2) shall not be deemed disqualified for nomination or appointment :

Provided that the Central Government may at any time before the expiration of the period of supersession, whether originally specified under sub-section (1) or as extended under this sub-section, take action under clause (*b*) of this sub-section.

Power of State Government to Supersede State Board

62. (1) If at any time the State Government is of opinion—

(*a*) that the State Board has persistently made default in the performance of the functions imposed on it by or under this Act ; or

(*b*) that circumstances exist which render it necessary in the public interest so to do,

the State Government may, by notification in the Official Gazette, supersede the State Board for such period, not exceeding one year, as may be specified in the notification :

Provided that before issuing a notification under this sub-section for the reasons mentioned in clause (*a*), the State Government shall give a reasonable opportunity to the State Board to show cause why it should not be superseded and shall consider the explanations and objections, if any, of the State Board.

(2) Upon the publication of a notification under sub-section (1) superseding the State Board, the provisions of sub-sections (2) and (3) of section 61 shall apply in relation to the supersession of the State Board as they apply in relation to the supersession of the Central Board or a Joint Board by the Central Government.

Power of Central Government to make Rules

63. (1) The Central Government may, simultaneously with the constitution of the Central Board, make rules in respect of the matters specified in sub-section (2) :

Provided that when the Central Board has been constituted, no such rule shall be made, varied, amended or repealed without consulting the Board.

(2) In particular, and without prejudice to the generality of the foregoing power, such rules may provide for all or any of the following matters, namely :—

(*a*) the terms and conditions of service of the members (other than the chairman and member-secretary) of the Central Board under sub-section (8) of section 5 ;

(*b*) the intervals and the time and place at which meetings of the Central Board or of any committee thereof constituted under this Act, shall be held and the procedure to be followed at such meetings, including the quorum necessary for the transaction of business under section 8, and under sub-section (2) of section 9 ;

(*c*) the fees and allowances to be paid to such members of a committee of the Central Board as are not members of the Board under sub-section (3) of section 9 ;

(*d*) the manner in which and the purposes for which persons may be associated with a Board under sub-section (1) of section 10 ;

(*e*) the terms and conditions of service of the chairman and the member-secretary of the Central Board under sub-section (9) of section 5 and under sub-section (1) of section 12 ;

(*f*) conditions subject to which a person may be appointed as a consulting engineer to the Central Board under sub-section (4) of section 12 ;

(*g*) the powers and duties to be exercised and performed by the chairman and the member-secretary of the Central Board ;

(*h*) the prohibition or regulation of bathing in any stream or well or the washing or cleaning therein of things of any class or description, or the putting of litter or other objectionable matter, whether poisonous, noxious or polluting or not into any stream or well ;

(*i*) the prohibition or regulation of the keeping or use, on any stream, of vessels provided with sanitary appliances from which polluting matter passes into the stream ;

(*j*) the form of the report of the Central Board analyst under sub-section (1) of section 22 ;

(*k*) the form of the report of the Government analyst under sub-section (3) of section 22 ;

(*l*) the form in which, and the time within which, the budget and annual report of the Central Board may be prepared and forwarded to the Central Government under sections 38 and 39 ;

(*m*) the form in which the accounts of the Central Board may be maintained under section 40 ;

(*n*) any other matter relating to the Central Board, including the powers and functions of that Board in relation to Union territories ;

(*o*) any other matter which has to be, or may be, prescribed.

(3) Every rule made by the Central Government under this Act shall be laid, as soon as may be after it is made, before each House of Parliament while it is in session for a total period of thirty days which may be comprised in one session or in two or more successive sessions, and if, before the expiry of the session in which it is so laid or the successive sessions aforesaid, both Houses agree in making any modification in the rule or both Houses agree that the rule should not be made, the rule shall thereafter have effect for in such modified form or be of no effect, as the case may be ; so, however, that any such modification or annulment shall be without prejudice to the validity of any thing previously done under that rule.

Power of State Government to Make Rules

64. (1) The State Government may, simultaneously with the constitution of the State Board, make rules to carry out the purposes of this Act in 23 respect of matters not falling within the purview of section 63 :

Provided that when, the State Board has been constituted, no such rule shall be made, varied, amended or repealed without consulting that Board.

(2) In particular, and without prejudice to the generality of the foregoing power, such rules may provide for all or any of the following matters, namely :—

(*a*) the terms and conditions of service of the members (other than the chairman and the member-secretary) of the State Board under sub-section (8) of section 5 ;

(*b*) the time and place of meetings of the State Board or of any committee of that Board constituted under this Act and the procedure to be followed at such meeting including the quorum necessary for the transaction of business under section 8 and under sub-section (2) of section 9 ;

(*c*) the fees and allowances to be paid to such members of a committee of the State Board as are not members of the Board under sub-section (2) of section 9 ;

(*d*) the manner in which and the purposes for which persons may be associated with the State Board under sub-section (1) of section 10 ;

(*e*) the terms and conditions of service of the chairman and the member-secretary of the State Board under sub-section (9) of section 5 and under sub-section (1) of section 12 ;

(*f*) the conditions subject to which a person may be appointed as a consulting engineer to the State Board under sub-section (4) of section 12 ;

(*g*) the powers and duties to be exercised and discharged by the chairman and the member-secretary of the State Board ;

(*h*) the form of the notice referred to in section 21 ;

(*i*) the form of the report of the State Board analyst under sub-section (1) of section 22 ;

(*j*) the form of the report of the Government analyst under sub-section (3) of section 22 ;

(*k*) the form of application for the consent of the State Board under sub-section (2) of section 25, and the particulars it may contain ;

(*l*) the manner in which inquiry under sub-section (3) of section 25 may be made in respect of an application for obtaining consent of the State Board and the matters to be taken into account in granting or refusing such consent ;

(*m*) the form and manner in which appeals may be filed, the fees payable in respect of such appeals and the procedure to be followed by the appellate authority in disposing of the appeals under sub-section (3) of section 28 ;

(*n*) the form in which, and the time within which, the budget and annual report of the State Board may be prepared and forwarded to the State Government under sections 38 and 39 ;

(*o*) the form in which the accounts of the State Board may be maintained under sub-section (1) of section 40 ;

(*p*) any other matter which has to be, or may be, prescribed.

MINISTRY OF WORKS AND HOUSING

NOTIFICATION

New Delhi, the 24th July, 1978

G.S.R. 378 (E)—In exercise of the powers conferred by section 17 of the Water (Prevention and Control of Pollution) Cess Act, 1977 (36 of 1977), the Central Government hereby makes the following rules, namely :—

1. Short title and commencement—(*a*) These rules may be called the Water (Prevention and Control of Pollution) Cess Rules 1978 ;

(*b*) They shall come into force on the date of their publication in the official Gazette.

2. Definition—In these rules, unless the context otherwise requires :—

(*a*) "Act" means the Water (Prevention and Control of Pollution) Cess Act, 1977 (36 of 1977) ;

(*b*) "assessing authority" means—

(*i*) in relation to Union Territory, the member-secretary of the Central Board ; and

(*ii*) in relation to a State, the member-secretary of the State Board ;

(*c*) "consumer" means a person or local authority by whom the cess under sub-section (1) of section 3 is payable under sub-section (2) of that section ;

(*d*) "form" means a form annexed to these rules ;

(*e*) "section" means a section of the Act ;

(*f*) "State Government" in relation to a Union Territory, means the Administrator thereof appointed under article 239 of the Constitution.

3. Standards of meters and places where they are to be affixed —(1) For the purposes of measuring and recording the quantity of water consumed, every consumer shall affix water meters, eventuri meters or orifice meters with integratory and recorders in conformity with the standards laid down by the Indian Standards Institution and where no standards have been laid down by that institution in conformity with such standards as may be specified by the Board.

(2) Wherever the meters referred to in sub-section (1) are not available, the consumer shall instal Vee notches or rectangular notches, with indicators and recorders or pressure gauges and pumping installations, after obtaining the permission of the assessing authority.

(3) Every consumer shall provide a separate meter for assessing the quantity of water used for each of the four purposes mentioned in column (1) of Schedule II to the Act.

(4) The maters shall be affixed at the entrance of the water supply connections within the premises of the consumer or at any other place to be approved by the assessing authority so that such meters are easily accessible for inspection and maintenance and for other purposes of the Act :

Provided that the place where is affixed shall, in no case be at a point before which water has been tapped by the consumer for utilisation for any purpose whatsoever.

4. Furnishing of returns—Every consumer shall furnish on or before the 5th of every calendar month, to the assesing authority, a return in Form I showing the quantity of water consumed in the previous month.

5. Manner of payment of the cess to the Central Government and the time within which it shall be paid.

(1) Every State Government shall remit to the Central Government, the amount of cess collected from the consumer before the 10th day of the calender month succeeding the month in which it is collected from the consumer.

(2) The amount of cess referred to in sub-rule (I) shall be remitted to the Central Government in the form of a bank draft drawn in favour of the Pay and Accounts Officer, Ministry of Works and Housing, New Delhi in whose books of accounts, the receipts would be adjusted finally.

(3) On receiving the bank draft, the Ministry on Works and Housing shall remit the same through a Challan into the Reserve Bank of India, New Delhi, for the purpose of crediting under relevant Major Head.

6. Rebate—Where a consumer instals any plant for the treatment of sewage or trade effluent, such consumer shall be entitled to the rebate under section 7 on and from the expiry of fifteen days from the date on which such plant is successfully commissioned and so long as it functions successfully.

7. Powers to be exercised by the Officer or the Authority of the State Government under section 9.

The officer or authority of the State Government specially empowered under section 9 shall have, in addition to the powers referred to in clauses (*a*) and (*b*) of that section, the power to :—

(*i*) inspect the manufacturing process or plant of the consumer ;

(*ii*) inspect the water supply system, and installations in the plant of the consumer ;

(*iii*) inspect waste treatment system and installations in the plant of the consumer ;

(*iv*) inspect the drainage system and installations including storm water disposal in the plant of the consumer ;

(*v*) call for and inspect records relating to the use and consumption of materials and water, and those relating to production, in the plant of the consumer ;

(*vi*) call for and inspect the records relating to power consumption in the plant of the consumer ; and

(*vii*) call for any other information on records relating to the supply, consumption and treatment of water in the plan ot the consumer.

8. Authority to impose penalty under section 11—the authority to impose penalty under section 11 shall be the assessing authority.

9. Appeal—(1) Any consumer aggrieved by an order of assessment made under section 6 or by an order imposing penalty made under section 11 may-appeal in form 11 annexed hereto, to at Committee (hereinafter referred to as the appellate committee) consisting of—

(*a*) where the assessing authority is the member-secretary of the Central Board, the Chairman of the Board, who shall be the Chairman of the Committee, and two members of that Board, to be nominated by the Chairman thereof :

(*b*) Where the assessing authority in the member secretary of the State Board, the Chairman of that Board, who shall be

the Chairman, of the Committee and two members of that Board, to be nominated by the Chairman thereof.

(2) Such appeal shall state the facts of the case and the ground relied upon by the appellant for preferring the appeal and shall be accompanied by a copy of the order of assessment made under section 6 or a copy of the order impasing penalty made under section 11, as the case may bc.

(3) Such appeal shall be preferred within a period of thirty days from the date of communications of the order of assessment or the order imposing penalty on the appellant :

Provided that if the Chairman of the appellate Committee is satisfied that there was good and sufficient reason for the delay in preferring the appeal, he may, for reasons to be recorded in willing, allow the appeal to be preferred after the expiry of the aforesaid period of thirty days and before the expiry of forty-five days from the date of communication of the order of assessment, or the order imposing penalty, on the appellant.

(4) Every appeal shall be accompainced by offices of rupees fifty.

[No. Q. 17013, 1778-EPC]
MIR NASRULLAII, Jt. Secy.

FORM I

(See Rule 4)

Return regarding Water consumed during the month of...........

Name and Address of the consumer	Purpose of which water consumed	Reading at the beginning of the first day of the calendar month under report	Reading at the end of the last day of calendar month under report	Quantity of water consumed in kilo litres.	If the mater was out of order the monthly average consumption of water for the previous 3 months of the working period	Quantity of water qualifing for rebate according to the assessee	Remarks (*)
1	2	3	4	5	6	7	8
	1. Industrial cooling spraying in mine pits or boiler feed.	(*i*) from Municipal water supply mains (*ii*) from well/tubewell (*iii*) from canal (*iv*) from river (*v*) from any other source					

2. Domestic purpose.	(*i*) from Municipal water supply mains (*ii*) from well/tubewell (*iii*) from Canal (*iv*) from river (*v*) from any other source
3. Processing whereby water gets polluted and the pollutants are easily biodegradable.	(*i*) from Municipal water supply mains (*ii*) from well/tubewell (*iii*) from Canal (*iv*) from river (*v*) from any other source
4. Processing whereby water gets polluted and the pollutants are not easily biodegradable and are toxic.	(*i*) from Municipal water supply mains (*ii*) from well/tubewell (*iii*) from Canal (*iv*) from river (*v*) from any other source

(*) for claiming rebate under col. 7 the assessee shall indicate in this column the analytical and other reports annaval to this return in support of this claim.

Signature of the consumer

Name

Address

ANNEXURE TO FORM I

Report of Analysis of Treated Effluent showing Performance of the Treatment Plant—For the month of...

Sample collected on...........
Sample tested on..............
By the laboratories...........

S.N.	Polluting parameters as mentiond in the conditions imposed under consent granted under section 25/26 of the Water (Prevention and Control of Pollution), Act, 1974	Maximum permissible limits or ranges allowed as per constet condition	Concentration of range of parameters as per report	Dates on which	
				There was breakdown or failure of the plant	On which underperformance was noticed
1	2	3	4	5	6

Each : Original Analysis report of Laboratory.

Signature...........
Date.................
Name...............
Address...........

FROM II

(See Rule 9)

FORM OF MEMORANDUM OF APPEAL

Before . . . . (**). . . . . . .

Here mention the name and designation of the authority.

Mamorandum of appeal under section 13 of the Water (Prevention and Control of Pollution) Cess Act, 1977.

Appeal No. . . . . , . . of 19

. . . .

. . . .

. . . .

Here furnish complete postal address

. . . . . Appellant

Vs.

. . . .

. . . .

. . . .

GROUNDS

(here mention the ground on which the appeal is made)

1.

2.

3.

4.

(**) here mention the name and designation of the authority.

PRAYER

In the light of what is stated above, the appellant respectfully prays that he/she/it may be exempted from the payment of Cess.

he/she/it may be allowed a rebate of 70 per cent as provided for, in the Act and the amount of Cess reduced to Rs. . . . .

the amount of Cess has not been correctly assessed and that it may be reduced to Rs. . . . . . .

the penalty imposed on him/her/it has been wrongfully imposed and should be set aside.

(here mention the name and designation of assessing authority).

. . . . .Respondent

The appellant named above, hegs to perfer this memorandum of appeal the order dated against . . . . . passed by. . . . . on the following facts and grounds :

FACTS

(here briefly mention the facts of the case)

the penalty imposed on him/her/it is excessive and should be suitably reduced on the basis of the facts as stated.

2. The amount of Rs. . . . . . (Rupees. . . . .) as fee for this appeal has been paid to . . . . .vide Receipt No. . . . . , ... dated. . . . .

Place : Signature of the Appellant

Name

Date : Address

· **R Chhatwal** He obtained his
from Roorkee University and
from Delhi University. He
20 years experience of teaching
uate, post-graduate and agricultu-
its. He has already edited "Encyclo-
Dictionary of Environment" and
clopaedia of Scientific and Technical
is."

Prof Mehra is teaching in the Chemistry Department, Universite' de Moncton, Canada for over two decades. He has worked in many analytical laboratories all over the world and published many papers in analytical chemistry.

M. Satake. Well known in the field of environmental Science. Prof. Satake is associated with Fukui University, Japan. He has vast experience of working in several laboratories in USA, Canada and Japan.

T. Katyal. She has done M.S. from University of Saskatchewan, Canada. At present she is teaching there and carrying out research jointly with Prof. J.B. Senior. Her main field of interest is Environmental Science.

Mohan M. Katyal. He has been teaching Chemistry at St. Stephen's college, University of Delhi, for the past three decades. A post-doctoral visiting scientist at various universities in Canada and Japan, he has published over 300 research papers, reviews, books and research monographs.

Prof. T. Nagahiro. He has been teaching engineering science at Himeji Institute of Technology, Japan for several years. His main field of research has been the application of environmental science in analytical chemistry.

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